Pawn

embedded scripting language

The Language

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ITB CompuPhase

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Table of contents

Foreword 1
A tutorial introduction 3
Data and declarations 61
Functions 70
The preprocessor 93
General syntax 97
Operators and expressions 105
Statements 113
Directives 118
Proposed function library 125
Pitfalls: differences from C 134
Assorted tips 137
Appendices 148
A: Error and warning messages 148
B: The compiler 169
C: Rationale 175
D: License 182
Index 185

Foreword

PAWN is a simple, typeless, 32-bit "scripting" language with a C-like syntax. Execution speed, stability, simplicity and a small footprint were essential design criteria for both the language and the interpreter/abstract machine that a PAWN program runs on.

An application or tool cannot do or be *everything* for *all* users. This not only justifies the diversity of editors, compilers, operating systems and many other software systems, it also explains the presence of extensive configuration options and macro or scripting languages in applications. My own applications have contained a variety of little languages; most were very simple, some were extensive... and most needs could have been solved by a general purpose language with a special purpose library. Hence, PAWN.

The PAWN language was designed as a flexible language for manipulating objects in a host application. The tool set (compiler, abstract machine) were written so that they were easily extensible and would run on different software/hardware architectures.

PAWN is a descendent of the original Small C by Ron Cain and James Hendrix, which at its turn was a subset of C. Some of the modifications that I did to Small C, e.g. the removal of the type system and the substitution of pointers by references, were so fundamental that I could hardly call my language a "subset of C" or a "C dialect" any more. Therefore, I stripped off the "C" from the title and used the name "SMALL" for the name of the language in my publication in Dr. Dobb's Journal and the years since. During development and maintenance of the product, I received many requests for changes. One of the frequently requested changes was to use a different name for the language —searching for information on the SMALL scripting language on the Internet was hindered by "small" being such a common word. The name change occurred together with a significant change in the language: the support of "states" (and state machines).

I am indebted to Ron Cain and James Hendrix (and more recently, Andy Yuen), and to Dr. Dobb's Journal to get this ball rolling. Although I must have touched nearly every line of the original code multiple times, the Small C origins are still clearly visible.

A detailed treatise of the design goals and compromises is in appendix C; here I would like to summarize a few key points. As written in the previous paragraphs, PAWN is for customizing applications (by writing scripts), not for writing applications. PAWN is weak on data structuring because PAWN programs are intended to manipulate objects (text, sprites, streams, queries, ...) in the host application, but the PAWN program is, *by intent*, denied direct access to any data outside its abstract machine. The only means that a PAWN program has to manipulate objects in the host application is by calling subroutines, so called "native functions", that the host application provides.

PAWN is flexible in that key area: *calling functions*. PAWN supports default values for any of the arguments of a function (not just the last), call-by-reference as well as call-by-value, and "named" as well as "positional" function arguments. PAWN does not have a "type checking" mechanism, by virtue of being a typeless language, but it *does* offer in replacement a "classification checking" mechanism, called "tags". The tag system is especially convenient for function arguments because each argument may specify multiple acceptable tags.

For any language, the power (or weakness) lies not in the individual features, but in their combination. For PAWN, I feel that the combination of named arguments —which lets you specify function arguments in any order, and default values —which allows you to skip specifying arguments that you are not interested in, blend together to a convenient and "descriptive" way to call (native) functions to manipulate objects in the host application.

A tutorial introduction

PAWN is a simple programming language with a syntax reminiscent to the "C" programming language. A PAWN program consists of a set of functions and a set of variables. The variables are data objects and the functions contain instructions (called "statements") that operate on the data objects or that perform tasks.

The first program in almost any computer language is one that prints a simple string; printing "Hello world" is a classic example. In PAWN, the program would look like:

Compiling and running scripts: see page 169

Listing: **hello.p**

```
main()
    printf "Hello world\n"
```

This manual assumes that you know how to run a PAWN program; if not, please consult the application manual (more hints are at page 169).

A PAWN program starts execution in an "entry" function* —in nearly all examples of this manual, this entry function is called "`main`". Here, the function `main` contains only a single instruction, which is at the line below the function head itself. Line breaks and indenting are insignificant; the invocation of the function `print` could equally well be on the same line as the head of function `main`.

The *definition* of a function requires that a pair of parentheses follow the function name. If a function takes parameters, their declarations appear between the parentheses. The function `main` does not take any parentheses. The rules are different for a function invocation (or a function *call*); parentheses are optional in the call to the `print` function.

The single argument of the `print` function is a string, which must be enclosed in double quotes. The characters `\n` near the end of the string form an *escape sequence*, in this case they indicate a "newline" symbol. When `print` encounters the newline escape sequence, it advances the cursor to the first column of the next line. One has to use the `\n` escape sequence to insert a "newline" into the string, because a string may not wrap over multiple lines.

String literals: 100

Escape sequence: 99

* This should not be confused with the "state" entry functions, which are called `entry`, but serve a different purpose —see page 41.

PAWN is a "case sensitive" language: upper and lower case letters are considered to be different letters. It would be an error to spell the function `printf` in the above example as "`PrintF`". Keywords and predefined symbols, like the name of function "`main`", must be typed in lower case.

If you know the C language, you may feel that the above example does not look much like the equivalent "Hello world" program in C/C++. PAWN can also look very similar to C, though. The next example program is also valid PAWN syntax (and it has the same semantics as the earlier example):

Listing: **hello.p — C style**

```
#include <console>

main()
{
    printf("Hello world\n");
}
```

These first examples also reveal a few differences between PAWN and the C language:

- ◇ there is usually no need to include any system-defined "header file";
- ◇ semicolons are optional (except when writing multiple statements on one line);
- ◇ when the body of a function is a single instruction, the braces (for a compound instruction) are optional;
- ◇ when you do not use the result of a function in an expression or assignment, parentheses around the function argument are optional.

As an aside, the few preceding points refer to *optional* syntaxes. It is your choice what syntax you wish to use: neither style is "deprecated" or "considered harmful". The examples in this manual position the braces and use an indentation that is known as the "Whitesmith's style", but PAWN is a free format language and other indenting styles are just as good.

Because PAWN is designed to be an *extension language* for applications, the function set/library that a PAWN program has at its disposal depends on the host application. As a result, the PAWN *language* has no intrinsic knowledge of *any* function. The `print` function, used in this first example, must be made available by the host application and be "declared" to the PAWN parser.[†] It is assumed, however, that all host applications provide a minimal

More function descriptions at page 125

[†] In the language specification, the term "parser" refers to any implementation that processes and runs on conforming Pawn programs —either interpreters or compilers.

set of common functions, like `print` and `printf`.

In some environments, the display or terminal must be enabled before any text can be output onto it. If this is the case, you must add a call to the function "`console`" before the first call to function `print` or `printf`. The `console` function also allows you to specify device characteristics, such as the number of lines and columns of the display. The example programs in this manual do not use the `console` functions, because many platforms do not require or provide it.

• Arithmetic

Fundamental elements of most programs are calculations, decisions (conditional execution), iterations (loops) and variables to store input data, output data and intermediate results. The next program example illustrates many of these concepts. The program calculates the greatest common divisor of two values using an algorithm invented by Euclides.

Listing: **gcd.p**

```
/*
  The greatest common divisor of two values,
  using Euclides' algorithm .
*/

main()
    {
    print "Input two values\n"
    new a = getvalue()
    new b = getvalue()
    while (a != b)
        if (a > b)
            a = a - b
        else
            b = b - a
    printf "The greatest common divisor is %d\n", a
    }
```

Function `main` now contains more than just a single "print" statement. When the body of a function contains more than one statement, these statements must be embodied in braces —the "`{`" and "`}`" characters. This groups the instructions to a single *compound statement*. The notion of grouping statements in a compound statement applies as well to the bodies of `if`–`else` and loop instructions.

Compound statement: 113

The `new` keyword creates a variable. The name of the variable follows `new`. It is common, but not imperative, to assign a value to the variable already at

Data declarations are covered in detail starting at page 61

the moment of its creation. Variables must be declared before they are used in an expression. The `getvalue` function (also common predefined function) reads in a value from the keyboard and returns the result. Note that PAWN is a *typeless* language, all variables are numeric cells that can hold a signed integral value.

The `getvalue` function name is followed by a pair of parentheses. These are *required* because the value that `getvalue` returns is stored in a variable. Normally, the function's arguments (or parameters) would appear between the parentheses, but `getvalue` (as used in this program) does not take any explicit arguments. If you do not assign the result of a function to a variable or use it in a expression in another way, the parentheses are optional. For example, the result of the `print` and `printf` statements are not used. You may still use parentheses around the arguments, but it is not required.

"while" loop: 117
"if–else": 115

Loop instructions, like "`while`", repeat a single instruction as long as the loop condition (the expression between parentheses) is "true". One can execute multiple instructions in a loop by grouping them in a compound statement. The `if`–`else` instruction has one instruction for the "true" clause and one for the "false".

Observe that some statements, like `while` and `if`–`else`, contain (or "fold around") another instruction —in the case of `if`–`else` even *two* other instructions. The complete bundle is, again, a single instruction. That is:

- ◇ the assignment statements "`a = a - b`" below the `if` and "`b = b - a`" below the `else` are statements;
- ◇ the `if`–`else` statement folds around these two assignment statements and forms a single statement of itself;
- ◇ the `while` statement folds around the `if`–`else` statement and forms, again, a single statement.

It is common to make the nesting of the statements explicit by indenting any sub-statements below a statement in the source text. In the "Greatest Common Divisor" example, the left margin indent increases by four space characters after the `while` statement, and again after the `if` and `else` keywords. Statements that belong to the same level, such as both `printf` invocations and the `while` loop, have the same indentation.

Relational operators: 108

The loop condition for the `while` loop is "`(a != b)`"; the symbol `!=` is the "not equal to" operator. That is, the `if`–`else` instruction is repeated until "`a`" equals "`b`". It is good practice to indent the instructions that run under control of another statement, as is done in the preceding example.

The call to `printf`, near the bottom of the example, differs from the `print` call right below the opening brace ("`{`"). The "`f`" in `printf` stands for "formatted", which means that the function can format and print numeric values and other data (in a user-specified format), as well as literal text. The `%d` symbol in the string is a token that indicates the position and the format that the subsequent argument to function `printf` should be printed. At run time, the token `%d` is replaced by the value of variable "`a`" (the second argument of `printf`).

Function `print` can only print text; it is quicker than `printf`. If you want to print a literal "%" at the display, you have to use `print`, or you have to double it in the string that you give to `printf`. That is:

```
print "20% of the personnel accounts for 80% of the costs\n"
```

and

```
printf "20%% of the personnel accounts for 80%% of the costs\n"
```

print the same string.

• Arrays & constants

Next to *simple* variables with a size of a single cell, PAWN supports "array variables" that hold many cells/values. The following example program displays a series of prime numbers using the well known "sieve of Eratosthenes". The program also introduces another new concept: symbolic constants. Symbolic constants look like variables, but they cannot be changed.

Listing: **sieve.p**

```
/* Print all primes below 100, using the "Sieve of Eratosthenes" */

main()
    {
    const max_primes = 100
    new series[max_primes] = { true, ... }

    for (new i = 2; i < max_primes; ++i)
        if (series[i])
            {
            printf "%d ", i
            /* filter all multiples of this "prime" from the list */
            for (new j = 2 * i; j < max_primes; j += i)
                series[j] = false
            }
    }
```

Constant declaration: 102

When a program or sub-program has some fixed limit built-in, it is good practice create a symbolic constant for it. In the preceding example, the symbol `max_primes` is a constant with the value 100. The program uses the symbol `max_primes` three times after its definition: in the declaration of the variable `series` and in both `for` loops. If we were to adapt the program to print all primes below 500, there is now only one line to change.

Progressive initiallers: 64

Like simple variables, arrays may be initialized upon creation. PAWN offers a convenient shorthand to initialize all elements to a fixed value: all hundred elements of the "`series`" array are set to `true` —without requiring that the programmer types in the word "`true`" a hundred times. The symbols `true` and `false` are predefined constants.

When a simple variable, like the variables `i` and `j` in the primes sieve example, is declared in the first expression of a `for` loop, the variable is valid only inside the loop. Variable declaration has its own rules; it is not a statement —although it looks like one. One of those rules is that the first expression of a `for` loop may contain a variable declaration.

"for" loop: 114

An overview of all operators: 105

Both `for` loops also introduce new operators in their third expression. The `++` operator increments its operand by one; meaning that, `++i` is equal to `i = i + 1`. The `+=` operator adds the expression on its right to the variable on its left; that is, `j += i` is equal to `j = j + i`.

There is an "off-by-one" issue that you need to be aware if when working with arrays. The first element in the `series` array is `series[0]`, so if the array holds `max_primes` elements, the last element in the array is `series[max_primes-1]`. If `max_primes` is 100, the last element, then, is `series[99]`. Accessing `series[100]` is invalid.

• Functions

Larger programs separate tasks and operations into functions. Using functions increases the modularity of programs and functions, when well written, are portable to other programs. The following example implements a function to calculate numbers from the Fibonacci series.

The Fibonacci sequence was discovered by Leonardo "Fibonacci" of Pisa, an Italian mathematician of the 13^{th} century—whose greatest achievement was popularizing for the Western world the Hindu-Arabic numerals. The goal of the sequence was to describe the growth of a population of (idealized)

rabbits; and the sequence is 1, 1, 2, 3, 5, 8, 13, 21,... (every next value is the sum of its two predecessors).

Listing: **fib.p**

```
/* Calculation of Fibonacci numbers by iteration */

main()
    {
    print "Enter a value: "
    new v = getvalue()
    if (v > 0)
        printf "The value of Fibonacci number %d is %d\n",
               v, fibonacci(v)
    else
        printf "The Fibonacci number %d does not exist\n", v
    }

fibonacci(n)
    {
    assert n > 0

    new a = 0, b = 1
    for (new i = 2; i < n; i++)
        {
        new c = a + b
        a = b
        b = c
        }
    return a + b
    }
```

The `assert` instruction at the top of the `fibonacci` function deserves explicit mention; it guards against "impossible" or invalid conditions. A negative Fibonacci number is *invalid*, and the `assert` statement flags it as a programmer's error if this case ever occurs. Assertions should only flag programmer's errors, never user input errors.

"assert" statement: 113

The implementation of a user-defined function is not much different than that of function `main`. Function `fibonacci` shows two new concepts, though: it receives an input value through a parameter and it returns a value (it has a "result").

Functions: properties & features: 70

Function parameters are declared in the function header; the single parameter in this example is "`n`". Inside the function, a parameter behaves as a local variable, but one whose value is passed from the outside at the *call* to the function.

The `return` statement ends a function and sets the result of the function. It need not appear at the very end of the function; early exits are permitted.

Native function interface: 85

The `main` function of the Fibonacci example calls predefined "native" functions, like `getvalue` and `printf`, as well as the user-defined function `fibonacci`. From the perspective of *calling* a function (as in function `main`), there is no difference between user-defined and native functions.

The Fibonacci numbers sequence describes a surprising variety of natural phenomena. For example, the two or three sets of spirals in pineapples, pine cones and sunflowers usually have consecutive Fibonacci numbers between 5 and 89 as their number of spirals. The numbers that occur naturally in branching patterns (e.g. that of plants) are indeed Fibonacci numbers. Finally, although the Fibonacci sequence is *not* a geometric sequence, the further the sequence is extended, the more closely the ratio between successive terms approaches the *Golden Ratio*, of 1.618...* that appears so often in art and architecture.

• Call-by-reference & call-by-value

Dates are a particularly rich source of algorithms and conversion routines, because the calenders that a date refers to have known such a diversity, through time and around the world.

The "Julian Day Number" is attributed to Josephus Scaliger† and it counts the number of days since November 24, 4714 BC (proleptic Gregorian calendar‡). Scaliger chose that date because it marked the coincidence of three well-established cycles: the 28-year Solar Cycle (of the old Julian calendar), the 19-year Metonic Cycle and the 15-year Indiction Cycle (periodic taxes or governmental requisitions in ancient Rome), and because no literature or recorded history was known to pre-date that particular date in the remote past. Scaliger used this concept to reconcile dates in historic documents,

* The exact value for the Golden Ratio is $1/2(\sqrt{5}+1)$. The relation between Fibonacci numbers and the Golden Ratio also allows for a "direct" calculation of any sequence number, instead of the iterative method described here.

† There is some debate on exactly *what* Josephus Scaliger invented and *who* or *what* he called it after.

‡ The Gregorian calendar was decreed to start on 15 October 1582 by pope Gregory XIII, which means that earlier dates do not really exist in the Gregorian calendar. When extending the Gregorian calendar to days before 15 October 1582, we refer to it as the *proleptic* Gregorian calendar.

later astronomers embraced it to calculate intervals between two events more easily.

Julian Day numbers (sometimes denoted with unit "JD") should not be confused with Julian Dates (the number of days since the start of the *same* year), or with the Julian calendar that was introduced by Julius Caesar.

Below is a program that calculates the Julian Day number from a date in the (proleptic) Gregorian calendar, and vice versa. Note that in the proleptic Gregorian calendar, the first year is 1 AD (Anno Domini) and the year before that is 1 BC (Before Christ): year zero does not exist! The program uses negative year values for BC years and positive (non-zero) values for AD years.

Listing: **julian.p**

```
/* calculate Julian Day number from a date, and vice versa */

main()
    {
    new d, m, y, jdn

    print "Give a date (dd-mm-yyyy): "
    d = getvalue(_, '-', '/')
    m = getvalue(_, '-', '/')
    y = getvalue()

    jdn = DateToJulian(d, m, y)
    printf("Date %d/%d/%d = %d JD\n", d, m, y, jdn)

    print "Give a Julian Day Number: "
    jdn = getvalue()
    JulianToDate jdn, d, m, y
    printf "%d JD = %d/%d/%d\n", jdn, d, m, y
    }

DateToJulian(day, month, year)
    {
    /* The first year is 1. Year 0 does not exist: it is 1 BC (or -1) */
    assert year != 0
    if (year < 0)
        year++

    /* move January and February to the end of the previous year */
    if (month <= 2)
        year--, month += 12
    new jdn = 365*year + year/4 - year/100 + year/400
              + (153*month - 457) / 5
              + day + 1721119
    return jdn
    }
```

```
JulianToDate(jdn, &day, &month, &year)
    {
    jdn -= 1721119

    /* approximate year, then adjust in a loop */
    year = (400 * jdn) / 146097
    while (365*year + year/4 - year/100 + year/400 < jdn)
        year++
    year--

    /* determine month */
    jdn -= 365*year + year/4 - year/100 + year/400
    month = (5*jdn + 457) / 153

    /* determine day */
    day = jdn - (153*month - 457) / 5

    /* move January and February to start of the year */
    if (month > 12)
        month -= 12, year++

    /* adjust negative years (year 0 must become 1 BC, or -1) */
    if (year <= 0)
        year--
    }
```

Function `main` starts with creating variables to hold the day, month and year, and the calculated Julian Day number. Then it reads in a date —three calls to `getvalue`— and calls function `DateToJulian` to calculate the day number. After calculating the result, `main` prints the date that you entered and the Julian Day number for that date. Now, let us focus on function `DateToJulian`...

Near the top of function `DateToJulian`, it increments the `year` value if it is negative; it does this to cope with the absence of a "zero" year in the proleptic Gregorian calendar. In other words, function `DateToJulian` modifies its function arguments (later, it also modifies `month`). Inside a function, an argument behaves like a local variable: you may modify it. These modifications remain local to the function `DateToJulian`, however. Function `main` passes the values of `d`, `m` and `y` into `DateToJulian`, who maps them to its function arguments `day`, `month` and `year` respectively. Although `DateToJulian` modifies `year` and `month`, it does not change `y` and `m` in function `main`; it only changes local copies of `y` and `m`. This concept is called "call by value".

"Call by value" versus "call by reference": 71

The example intentionally uses different names for the local variables in the functions `main` and `DateToJulian`, for the purpose of making the above

explanation easier. Renaming `main`'s variables `d`, `m` and `y` to `day`, `month` and `year` respectively, does not change the matter: then you just happen to have two local variables called `day`, two called `month` and two called `year`, which is perfectly valid in PAWN.

The remainder of function `DateToJulian` is, regarding the PAWN language, uninteresting arithmetic.

Returning to the second part of the function `main` we see that it now asks for a day number and calls another function, `JulianToDate`, to find the date that matches the day number. Function `JulianToDate` is interesting because it takes one input argument (the Julian Day number) and needs to calculate three output values, the day, month and year. Alas, a function can only have a single return value —that is, a `return` statement in a function may only contain *one* expression. To solve this, `JulianToDate` specifically requests that changes that it makes to some of its function arguments are copied back to the variables of the caller of the function. Then, in `main`, the variables that must hold the result of `JulianToDate` are passed as arguments to `JulianToDate`.

Function `JulianToDate` marks the appropriate arguments for being "copied back to caller" by prefixing them with an `&` symbol. Arguments with an `&` are copied back, arguments without is are not. "Copying back" is actually not the correct term. An argument tagged with an `&` is passed to the function in a special way that allows the function to directly modify the original variable. This is called "call by reference" and an argument that uses it is a "reference argument".

In other words, if `main` passes `y` to `JulianToDate` —who maps it to its function argument `year`— and `JulianToDate` changes `year`, then `JulianToDate` *really* changes `y`. Only through reference arguments can a function directly modify a variable that is declared in a different function.

To summarize the use of call-by-value versus call-by-reference: if a function has one output value, you typically use a `return` statement; if a function has more output values, you use reference arguments. You may combine the two inside a single function, for example in a function that returns its "normal" output via a reference argument and an error code in its return value.

As an aside, many desktop application use conversions to and from Julian Day numbers (or varieties of it) to conveniently calculate the number of days between to dates or to calculate the date that is 90 days from now

—for example.

• Rational numbers

All calculations done up to this point involved only whole numbers —integer values. PAWN also has support for numbers that can hold fractional values: these are called "rational numbers". However, whether this support is enabled depends on the host application.

Rational numbers can be implemented as either floating-point or fixed-point numbers. Floating-point arithmetic is commonly used for general-purpose and scientific calculations, while fixed-point arithmetic is more suitable for financial processing and applications where rounding errors should not come into play (or at least, they should be predictable). The PAWN toolkit has both a floating-point and a fixed-point module, and the details (and trade-offs) for these modules in their respective documentation. The issue is, however, that a host application may implement *either* floating-point *or* fixed-point, *or* both *or* neither.* The program below requires that at least either kind of rational number support is available; it will fail to run if the host application does not support rational numbers at all.

Listing: **c2f.p**

```
#include <rational>

main()
    {
    new Rational: Celsius
    new Rational: Fahrenheit

    print "Celsius\t Fahrenheit\n"
    for (Celsius = 5; Celsius <= 25; Celsius++)
        {
        Fahrenheit = (Celsius * 1.8) + 32
        printf "%r \t %r\n", Celsius, Fahrenheit
        }
    }
```

The example program converts a table of degrees Celsius to degrees Fahrenheit. The first directive of this program is to import definitions for rational number support from an include file. The file "`rational`" includes either

* Actually, this is already true of *all* native functions, including all native functions that the examples in this manual use.

support for floating-point numbers or for fixed-point numbers, depending on what is available.

Tag names: 67

The variables `Celsius` and `Fahrenheit` are declared with a tag "`Rational:`" between the keyword `new` and the variable name. A tag name denotes the purpose of the variable, its permitted use and, as a special case for rational numbers, its memory lay-out. The `Rational:` tag tells the PAWN parser that the variables `Celsius` and `Fahrenheit` contain fractional values, rather than whole numbers.

The equation for obtaining degrees Fahrenheit from degrees Celsius is

$$^{\circ}F = \frac{9}{5} + 32\ ^{\circ}C$$

The program uses the value 1.8 for the quotient $9/5$. When rational number support is enabled, PAWN supports values with a fractional part behind the decimal point.

The only other non-trivial change from earlier programs is that the format string for the `printf` function now has variable placeholders denoted with "`%r`" instead of "`%d`". The placeholder `%r` prints a rational number at the position; `%d` is only for integers ("whole numbers").

I used the include file "`rational`" rather than "`float`" or "`fixed`" in an attempt to make the example program portable. If you know that the host application supports floating point arithmetic, it may be more convenient to "#include" the definitions from the file `float` and use the tag `Float:` instead of `Rational` —when doing so, you should also replace `%r` by `%f` in the call to `printf`. For details on fixed point and floating point support, please see the application notes "Fixed Point Support Library" and "Floating Point Support Library" that are available separately.

• Strings

PAWN has no intrinsic "string" type; character strings are stored in arrays, with the convention that the array element behind the last valid character is zero. Working with strings is therefore equivalent with working with arrays.

Among the simplest of encryption schemes is the one called "ROT13" — actually the algorithm is quite "weak" from a cryptographical point of view. It is most widely used in public electronic forums (BBSes, Usenet) to hide

texts from casual reading, such as the solution to puzzles or riddles. ROT13 simply "rotates" the alphabet by half its length, i.e. 13 characters. It is a symmetric operation: applying it twice on the same text reveals the original.

Listing: **rot13.p**

```
/* Simple encryption, using ROT13 */

main()
    {
    printf "Please type the string to mangle: "

    new str[100]
    getstring str, sizeof str
    rot13 str

    printf "After mangling, the string is: \"%s\"\n", str
    }

rot13(string[])
    {
    for (new index = 0; string[index]; index++)
        if ('a' <= string[index] <= 'z')
            string[index] = (string[index] - 'a' + 13) % 26 + 'a'
        else if ('A' <= string[index] <= 'Z')
            string[index] = (string[index] - 'A' + 13) % 26 + 'A'
    }
```

In the function header of `rot13`, the parameter "`string`" is declared as an array, but without specifying the size of the array —there is no value between the square brackets. When you specify a size for an array in a function header, it must match the size of the *actual* parameter in the function call. Omitting the array size specification in the function header removes this restriction and allows the function to be called with arrays of any size. You must then have some other means of determining the (maximum) size of the array. In the case of a string parameter, one can simply search for the zero terminator.

The `for` loop that walks over the string is typical for string processing functions. Note that the loop condition is "`string[index]`". The rule for true/false conditions in PAWN is that any value is "true", except zero. That is, when the array cell at `string[index]` is zero, it is "false" and the loop aborts.

The ROT13 algorithm rotates only letters; digits, punctuation and special characters are left unaltered. Additionally, upper and lower case letters must be handled separately. Inside the `for` loop, two `if` statements filter out the characters of interest. The way that the second `if` is chained to the "else"

clause of the first `if` is noteworthy, as it is a typical method of testing for multiple non-overlapping conditions.

Earlier in this chapter, the concept of "call by value" versus "call by reference" were discussed. When you are working with strings, or arrays in general, note that PAWN *always* passes arrays *by reference*. It does this to conserve memory and to increase performance —arrays can be large data structures and passing them by value requires a copy of this data structure to be made, taking both memory and time. Due to this rule, function `rot13` can modify its function parameter (called "`string`" in the example) without needing to declare as a reference argument.

A function that takes an array as an argument and that does not change it, may mark the argument as "`const`"; see page 72

Another point of interest are the conditions in the two `if` statements. The first `if`, for example, holds the condition "`'a' <= string[index] <= 'z'`", which means that the expression is true if (and only if) both `'a' <= string[index]` *and* `string[index] <= 'z'` are true. In the combined expression, the relational operators are said to be "chained", as they chain multiple comparisons in one condition.

Relational operators: 108

Finally, note how the last `printf` in function `main` uses the escape sequence `\"` to print a double quote. Normally a double quote ends the literal string; the escape sequence "`\"`" inserts a double quote into the string.

Escape sequence: 99

❖

Staying on the subject of strings and arrays, below is a program that separates a string of text into individual words and counts them. It is a simple program that shows a few new features of the PAWN language.

Listing: **wcount.p**

```
/* word count: count words on a string that the user types */

main()
    {
    print "Please type a string: "
    new string[100]
    getstring string, sizeof string

    new count = 0

    new word[20]
    new index
    for ( ;; )
        {
        word = strtok(string, index)
        if (strlen(word) == 0)
            break
        count++
```

```
        printf "Word %d: '%s'\n", count, word
        }

    printf "\nNumber of words: %d\n", count
    }

strtok(const string[], &index)
    {
    new length = strlen(string)

    /* skip leading white space */
    while (index < length && string[index] <= ' ')
        index++

    /* store the word letter for letter */
    new offset = index                /* save start position of token */
    new result[20]                    /* string to store the word in */
    while (index < length
           && string[index] > ' '
           && index - offset < sizeof result - 1)
        {
        result[index - offset] = string[index]
        index++
        }
    result[index - offset] = EOS      /* zero-terminate the string */

    return result
    }
```

"for" loop: 114

Function `main` first displays a message and retrieves a string that the user must type. Then it enters a loop: writing "`for (;;)`" creates a loop without initialisation, without increment and without test —it is an infinite loop, equivalent to "`while (true)`". However, where the PAWN parser will give you a warning if you type "`while (true)`" (something along the line "redundant test expression; always true"), "`for (;;)`" passes the parser without warning.

A typical use for an infinite loop is a case where you need a loop with the test in the middle —a hybrid between a `while` and a `do...while` loop, so to speak. PAWN does not support loops-with-a-test-in-the middle directly, but you can imitate one by coding an infinite loop with a conditional `break`. In this example program, the loop:

- ◇ gets a word from the string —*code before the test*;
- ◇ tests whether a new word is available, and breaks out of the loop if not —*the test in the middle*;
- ◇ prints the word and its sequence number —*code after the test*.

As is apparent from the line "`word = strtok(string, index)`" (and the declaration of variable `word`), PAWN supports array assignment and functions returning arrays. The PAWN parser verifies that the array that `strtok` returns has the same size and dimensions as the variable that it is assigned into.

Function `strlen` is a native function (predefined), but `strtok` is not: it must be implemented by ourselves. The function `strtok` was inspired by the function of the same name from C/C++, but it does not modify the source string. Instead it copies characters from the source string, word for word, into a local array, which it then returns.

• Arrays and enumerations (structured data)

In a typeless language, we might assign a different purpose to some array elements than to other elements in the same array. PAWN supports enumerated constants with an extension that allows it to mimic some functionality that other languages implement with "structures" or "records".

The example to illustrate enumerations and arrays is longer than previous PAWN programs, and it also displays a few other features, such as global variables and named parameters.

Listing: **queue.p**

```
/* Priority queue (for simple text strings) */
#include <string>

enum message
    {
    text[40 char],
    priority
    }

main()
    {
    new msg[message]

    /* insert a few items (read from console input) */
    printf "Please insert a few messages and their priorities; \
            end with an empty string\n"
    for ( ;; )
        {
        printf "Message:  "
        getstring .string = msg[text], .maxlength = 40, .pack = true
        if (strlen(msg[text]) == 0)
            break
        printf "Priority: "
        msg[priority] = getvalue()
```

```
        if (!insert(msg))
            {
            printf "Queue is full, cannot insert more items\n"
            break
            }
        }

    /* now print the messages extracted from the queue */
    printf "\nContents of the queue:\n"
    while (extract(msg))
        printf "[%d] %s\n", msg[priority], msg[text]
    }

const queuesize = 10
new queue[queuesize][message]
new queueitems = 0

insert(const item[message])
    {
    /* check if the queue can hold one more message */
    if (queueitems == queuesize)
        return false            /* queue is full */

    /* find the position to insert it to */
    new pos = queueitems        /* start at the bottom */
    while (pos > 0 && item[priority] > queue[pos-1][priority])
        --pos                   /* higher priority: move up a slot */

    /* make place for the item at the insertion spot */
    for (new i = queueitems; i > pos; --i)
        queue[i] = queue[i-1]

    /* add the message to the correct slot */
    queue[pos] = item
    queueitems++

    return true
    }

extract(item[message])
    {
    /* check whether the queue has one more message */
    if (queueitems == 0)
        return false            /* queue is empty */

    /* copy the topmost item */
    item = queue[0]
    --queueitems

    /* move the queue one position up */
    for (new i = 0; i < queueitems; ++i)
        queue[i] = queue[i+1]

    return true
    }
```

Near the top of the program listing is the declaration of the enumeration `message`. This enumeration defines two constants: `text`, which is zero, and `priority`, which is 10 (assuming a 32-bit cell). The idea behind an enumeration is to quickly define a list of symbolic constants without duplicates. By default, every constant in the list is 1 higher than its predecessor and the very first constant in the list is zero. However, you may give an *extra* increment for a constant so that the successor has a value of 1 plus that extra increment. The `text` constant specifies an extra increment of `40 char`. In PAWN, `char` is an operator, it returns the number of cells needed to hold a packed string of the specified number of characters. Assuming a 32-bit cell and a 8-bit character, 10 cells can hold 40 packed characters.

"enum" statement: 102

"char" operator: 111

Immediately at the top of function `main`, a new array variable is declared with the size of `message`. The symbol `message` is the name of the enumeration. It is also a constant with the value of the last constant in the enumeration list plus the optional extra increment for that last element. So in this example, `message` is 11. That is to say, array `msg` is declared to hold 11 cells.

Further in `main` are two loops. The `for` loop reads strings and priority values from the console and inserts them in a queue. The `while` loop below that extracts element by element from the queue and prints the information on the screen. The point to note, is that the `for` loop stores both the string and the priority number (an integer) in the same variable `msg`; indeed, function `main` declares only a single variable. Function `getstring` stores the message text that you type starting at array `msg[text]` while the priority value is stored (by an assignment a few lines lower) in `msg[priority]`. The `printf` function in the `while` loop reads the string and the value from those positions as well.

At the same time, the `msg` array is an entity on itself: it is passed in its entirety to function `insert`. That function, in turn, says near the end "`queue[queueitems] = item`", where `item` is an array with size `message` and `queue` is a two-dimensional array that holds `queuesize` elements of size `message`. The declaration of `queue` and `queuesize` are just above function `insert`.

The example implements a "priority queue". You can insert a number of messages into the queue and when these messages all have the same priority, they are extracted from the queue in the same order. However, when the messages have different priorities, the one with the highest priority comes

out first. The "intelligence" for this operation is inside function `insert`: it first determines the position of the new message to add, then moves a few messages one position upward to make space for the new message. Function `extract` simply always retrieves the first element of the queue and shifts all remaining elements down by one position.

Note that both functions `insert` and `extract` work on two shared variables, `queue` and `queueitems`. A variable that is declared inside a function, like variable `msg` in function `main` can only be accessed from within that function. A "global variable" is accessible by *all* functions, and that variable is declared outside the scope of any function. Variables must still be declared before they are used, so `main` cannot access variables `queue` and `queueitems`, but both `insert` and `extract` can.

Function `extract` returns the messages with the highest priority via its function argument `item`. That is, it changes its function argument by copying the first element of the `queue` array into `item`. Function `insert` copies in the other direction and it does not change its function argument `item`. In such a case, it is advised to mark the function argument as "`const`". This helps the PAWN parser to both check for errors and to generate better (more compact, quicker) code.

Named parameters: 74

A final remark on this latest sample is the call to `getstring` in function `main`: note how the parameters are attributed with a description. The first parameter is labelled "`.string`", the second "`.maxlength`" and the third "`.pack`". Function `getstring` receives "named parameters" rather than positional parameters. The order in which named parameters are listed is not important. Named parameters are convenient in specifying —and deciphering— long parameter lists.

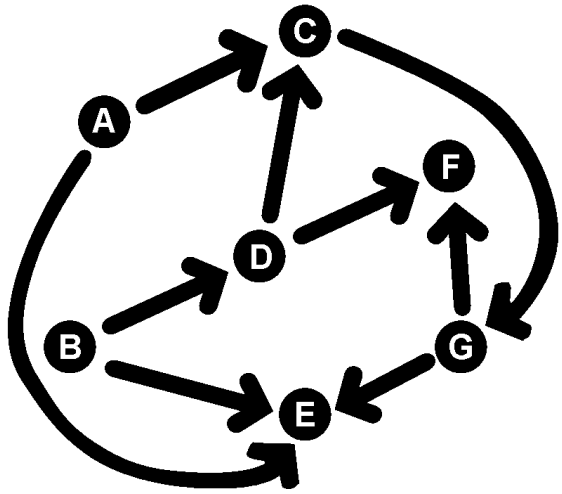
• Bit operations to manipulate "sets"

A few algorithms are most easily solved with "set operations", like intersection, union and inversion. In the figure below, for example, we want to design an algorithm that returns us the points that can be reached from some other point in a specified maximum number of steps. For example, if we ask it to return the points that can be reached in two steps starting from **B**, the algorithm has to return **C**, **D**, **E** and **F**, but not **G** because **G** takes three steps from **B**.

Our approach is to keep, for each point in the graph, the set of other points

that it can reach in *one* step —this is the "`next_step`" set. We also have a "`result`" set that keeps all points that we have found so far. We start by setting the `result` set equal to the `next_step` set for the departure point. Now we have in the `result` set all points that one can reach in one step. Then, for every point in our `result` set, we create a union of the `result` set and the `next_step` set for that point. This process is iterated for a specified number of loops.

An example may clarify the procedure outlined above. When the departure point is **B**, we start by setting the `result` set to **D** and **E** —these are the points that one can reach from **B** in one step. Then, we walk through the `result` set. The first point that we encounter in the set is **D**, and we check what points can be reached from **D** in one step: these are **C** and **F**. So we add **C** and **F** to the `result` set. We knew that the points that can be reached from **D** in one step are **C** and **F**, because **C** and **F** are in the `next_step` set for **D**. So what we do is to merge the `next_step` set for point **D** into the `result` set. The merge is called a "union" in set theory. That handles **D**. The original `result` set also contained point **E**, but the `next_step` set for **E** is empty, so no more point is added. The new `result` set therefore now contains **C**, **D**, **E** and **F**.



A set is a general purpose container for elements. The only information that a set holds of an element is whether it is present in the set or not. The order of elements in a set is insignificant and a set cannot contain the same element multiple times. The PAWN language does not provide a "set" data type or

operators that work on sets. However, sets with up to 32 elements can be simulated by bit operations. It takes just one bit to store a "present/absent" status and a 32-bit cell can therefore maintain the status for 32 set elements —provided that each element is assigned a unique bit position.

The relation between set operations and bitwise operations is summarized in the following table. In the table, an upper case letter stands for a set and a lower case letter for an element from that set.

concept	**mathematical notation**	PAWN **expression**
intersection	$A \cap B$	`A & B`
union	$A \cup B$	`A | B`
complement	$\overline{A}$	`~A`
empty set	ε	`0`
membership	$x \in A$	`(1 << x) & A`

To test for membership —that is, to query whether a set holds a particular element, create a set with just one element and take the intersection. If the result is `0` (the empty set) the element is not in the set. Bit numbering starts typically at zero; the lowest bit is bit `0` and the highest bit in a 32-bit cell is bit `31`. To make a cell with only bit `7` set, shift the value `1` left by seven —or in a PAWN expression: "`1 << 7`".

Below is the program that implements the algorithm described earlier to find all points that can be reached from a specific departure in a given number of steps. The algorithm is completely in the `findtargets` function.

Listing: **set.p**

```
/* Set operations, using bit arithmetic */

main()
    {
    enum (<<= 1) { A = 1, B, C, D, E, F, G }
    new nextstep[] =
        { C | E,     /* A can reach C and E */
          D | E,     /* B  "    "   D and E */
          G,         /* C  "    "   G */
          C | F,     /* D  "    "   C and F */
          0,         /* E  "    "   none */
          0,         /* F  "    "   none */
          E | F,     /* G  "    "   E and F */
        }
    #pragma unused A, B
```

```
    print "The departure point: "
    new start = clamp( .value = toupper(getchar()) - 'A',
                       .min = 0,
                       .max = sizeof nextstep - 1
                     )

    print "\nThe number of steps: "
    new steps = getvalue()

    /* make the set */
    new result = findtargets(start, steps, nextstep)
    printf "The points in range of %c in %d steps: ", start + 'A', steps
    for (new i = 0; i < sizeof nextstep; i++)
        if (result & 1 << i)
            printf "%c ", i + 'A'
    }

findtargets(start, steps, nextstep[], numpoints = sizeof nextstep)
    {
    new result = 0
    new addedpoints = nextstep[start]
    while (steps-- > 0 && result != addedpoints)
        {
        result = addedpoints
        for (new i = 0; i < numpoints; i++)
            if (result & 1 << i)
                addedpoints |= nextstep[i]
        }
    return result
    }
```

The `enum` statement just below the header of the `main` function declares the constants for the nodes `A` to `G`, but with a twist. Usually, the enum starts counting from zero; here, the value of the first constant, `A`, is explicitly set to 1. More noteworthy is the expression "`(<<= 1)`" between the `enum` keyword and the opening brace that starts the constant list: it specifies a "bit shifting" increment. By default, every constant in an `enum` list gets a value that is 1 above its predecessor, but you can specify every successive constant in an enumeration to have a value that is:

"enum" statement: 102

◇ its predecessor incremented by any value (not just 1) —e.g., "`(+= 5)`";

◇ its predecessor multiplied by any value —e.g., "`(*= 3)`";

◇ its predecessor bit-shifted to the left by any value —e.g., "`(<<= 1)`";

Note that, in binary arithmetic, shifting left by one bit amounts to the same as multiplying by two, meaning that "`(*= 2)`" and "`(<<= 1)`" do the same thing.

"cellbits" constant: 103

When working with sets, a typical task that pops up is to determine the number of elements in the set. A straightforward function that does this is below:

Listing: **simple bitcount function**

```
bitcount(set)
    {
    new count = 0
    for (new i = 0; i < cellbits; i++)
        if (set & (1 << i))
            count++
    return count
    }
```

With a cell size of 32 bits, this function's loop iterates 32 times to check for a single bit at each iteration. With a bit of binary arithmetic magic, we can reduce it to loop only for the number of bits that are "set". That is, the following function iterates only once if the input value has only one bit set:

Listing: **improved bitcount function**

```
bitcount(set)
    {
    new count = 0
    if (set)
        do
            count++
        while ((set = set & (set - 1)))
    return count
    }
```

• A simple RPN calculator

Algebraic notation is also called "infix" notation

The common mathematical notation, with expressions like "$26-3\times(5+2)$", is known as the *algebraic* notation. It is a compact notation and we have grown accustomed to it. PAWN and by far most other programming languages use the algebraic notation for their programming expressions. The algebraic notation does have a few disadvantages, though. For instance, it occasionally *requires* that the order of operations is made explicit by folding a part of the expression in parentheses. The expression at the top of this paragraph *can* be rewritten to eliminate the parentheses, but at the cost of nearly doubling its length. In practice, the algebraic notation is augmented with precedence level rules that say, for example, that multiplication goes before

addition and subtraction.* Precedence levels greatly reduce the need for parentheses, but it does not fully avoid them. Worse is that when the number of operators grows large, the hierarchy of precedence levels and the particular precedence level for each operator becomes hard to memorize —which is why an operator-rich language as APL does away with precedence levels altogether.

Around 1920, the Polish mathematician Jan Łukasiewicz demonstrated that by putting the operators in front of their operands, instead of between them, precedence levels became redundant and parentheses were never necessary. This notation became known as the "Polish Notation".† Charles Hamblin proposed later to put operators *behind* the operands, calling it the "Reverse Polish Notation". The advantage of *reversing* the order is that the operators are listed in the same order as they must be executed: when reading the operators from the left to the right, you also have the operations to perform in that order. The algebraic expression from the beginning of this section would read in RPN as:

Reverse Polish Notation is also called "postfix" notation

$$26\ 3\ 5\ 2\ +\ \times\ -$$

When looking at the operators only, we have: first an addition, then a multiplication and finally a subtraction. The operands of each operator are read from right to left: the operands for the + operator are the values 5 and 2, those for the × operator are the result of the previous addition and the value 3, and so on.

It is helpful to imagine the values to be stacked on a pile, where the operators take one or more operands from the top of the pile and put a result back on top of the pile. When reading through the RPN expression, the values 26, 3, 5 and 2 are "stacked" in that order. The operator + removes the top two elements from the stack (5 and 2) and pushes the sum of these values back —the stack now reads "26 3 7". Then, the × operator removes 3 and 7 and pushes the product of the values onto the stack —the stack is "26 21". Finally, the − operator subtracts 21 from 26 and stores the single value 5, the end result of the expression, back onto the stack.

* These rules are often summarized in a mnemonic like "Please Excuse My Dear Aunt Sally" (Parentheses, Exponentiation, Multiplication, Division, Addition, Subtraction).

† Polish Notation is completely unrelated to "Hungarian Notation" —which is just the habit of adding "type" or "purpose" identification warts to names of variables or functions.

Reverse Polish Notation became popular because it was easy to understand and easy to implement in (early) calculators. It also opens the way to operators with more than two operands (e.g. integration) or operators with more than one result (e.g. conversion between polar and Cartesian coordinates).

The main program for a Reverse Polish Notation calculator is below:

Listing: **rpn.p**

```
/* a simple RPN calculator */
#include strtok
#include stack
#include rpnparse

main()
    {
    print "Type expressions in Reverse Polish Notation " ...
          "(or an empty line to quit)\n"
    new string[100]
    while (getstring(string, sizeof string))
        rpncalc string
    }
```

The main program contains very little code itself; instead it *includes* the required code from three other files, each of which implements a few functions that, together, build the RPN calculator. When programs or scripts get larger, it is usually advised to spread the implementation over several files, in order to make maintenance easier.

Function `main` first puts up a prompt and calls the native function `getstring` to read an expression that the user types. Then it calls the custom function `rpncalc` to do the real work. Function `rpncalc` is implemented in the file `rpnparse.inc`, reproduced below:

Listing: **rpnparse.inc**

```
/* main rpn parser and lexical analysis, part of the RPN calculator */
#include <rational>
#include <string>

enum token
    {
              t_type,           /* operator or token type */
    Rational: t_value,          /* value, if t_type is "Number" */
              t_word[20],       /* raw string */
    }

const Number    = '0'
const EndOfExpr = '#'
```

```
rpncalc(const string[])
    {
    new index
    new field[token]
    for ( ;; )
        {
        field = gettoken(string, index)
        switch (field[t_type])
            {
            case Number:
                push field[t_value]
            case '+':
                push pop() + pop()
            case '-':
                push - pop() + pop()
            case '*':
                push pop() * pop()
            case '/', ':':
                push 1.0 / pop() * pop()
            case EndOfExpr:
                break   /* exit "for" loop */
            default:
                printf "Unknown operator '%s'\n", field[t_word]
            }
        }
    printf "Result = %r\n", pop()
    if (clearstack())
        print "Stack not empty\n", red
    }

gettoken(const string[], &index)
    {
    /* first get the next "word" from the string */
    new word[20]
    word = strtok(string, index)

    /* then parse it */
    new field[token]
    field[t_word] = word
    if (strlen(word) == 0)
        {
        field[t_type] = EndOfExpr /* special "stop" symbol */
        field[t_value] = 0
        }
    else if ('0' <= word[0] <= '9')
        {
        field[t_type] = Number
        field[t_value] = rval(word)
        }
    else
        {
```

```
        field[t_type] = word[0]
        field[t_value] = 0
        }

    return field
    }
```

Rational numbers, see also the "Celsius to Fahrenheit" example on page page 14

The RPN calculator uses rational number support and `rpnparse.inc` includes the "`rational`" file for that purpose. Almost all of the operations on rational numbers is hidden in the arithmetic. The only direct references to rational numbers are the "`%r`" format code in the `printf` statement near the bottom of function `rpncalc` and the call to `rationalstr` halfway function `gettoken`.

"enum" statement: 102

The first remarkable element in the file `rpnparse.inc` is the `enum` declaration, where one element has a tag (`t_value`) and the other element has a size (`t_word`). Function `rpncalc` declares variable `field` as an array using the enumeration symbol as its size. Behind the screens, this declaration does more than just create an array with 22 cells:

Another example of an index tag: page 67

- ◇ The index tag of the array is set to the tag name "`token:`". This means that you can index the array with any of the elements from the enumeration, but not with values that have a different tag. In other words, `field[t_type]` is okay, but `field[1]` gives a parser diagnostic.
- ◇ The tag name of the enumeration overrules the tag name of the array variable, if any. The `field` variable is untagged, but `field[t_value]` has the tag `Rational:`, because the enumeration element `t_value` is declared as such. This, hence, allows you to create an array whose elements have different tag names.
- ◇ When the enumeration element has a size, the array element indicated with that element is sometimes treated as a sub-array. In `rpncalc`, expression "`field[t_type]`" is a single cell, "`field[t_value]`" is a single cell, but "`field[t_word]`" is a one-dimensional array of 20 cells. We see that specifically in the line:

  ```
  printf "Unknown operator '%s'\n", field[t_word]
  ```

  where the format code `%s` expects a string —a zero-terminated array.

"switch" statement: page 116

If you know C/C++ or Java, you may want to look at the `switch` statement. The `switch` statement differs in a number of ways from the other languages that provide it. The cases are not fall-through, for example, which in turn means that the `break` statement for the `case EndOfExpr` breaks out of the enclosing loop, instead of out of the `switch`.

On the top of the `for` loop in function `rpncalc`, you will find the instruction "`field = gettoken(string, index)`". As already exemplified in the `wcount.p` ("word count") program on page 17, functions may return arrays. It gets more interesting for a similar line in function `gettoken`:

```
field[t_word] = word
```

where `word` is an array of 20 cells and `field` is an array of 22 cells. However, as the `t_word` enumeration field is declared as having a size of 20 cells, "`field[t_word]`" is considered a sub-array of 20 cells, precisely matching the array size of `word`.

Listing: **strtok.inc**

```
/* extract words from a string (words are separated by white space) */
#include <string>

strtok(const string[], &index)
    {
    new length = strlen(string)

    /* skip leading white space */
    while (index < length && string[index] <= ' ')
        index++

    /* store the word letter for letter */
    new offset = index              /* save start position of token */
    new result[20]                  /* string to store the word in */
    while (index < length
           && string[index] > ' '
           && index - offset < sizeof result - 1)
        {
        result[index - offset] = string[index]
        index++
        }
    result[index - offset] = EOS    /* zero-terminate the string */

    return result
    }
```

Function `strtok` is the same as the one used in the `wcount.p` example. It is implemented in a separate file for the RPN calculator program. Note that the `strtok` function as it is implemented here can only handle words with up to 19 characters —the 20^{th} character is the zero terminator. A truly general purpose re-usable implementation of an `strtok` function would pass the destination array as a parameter, so that it could handle words of any size. Supporting both packed and unpack strings would also be a useful feature of a general purpose function.

wcount.p: page 17

When discussing the merits of Reverse Polish Notation, I mentioned that a stack is both an aid in "visualizing" the algorithm as well as a convenient

method to implement an RPN parser. This example RPN calculator, uses a stack with the ubiquitous functions `push` and `pop`. For error checking and resetting the stack, there is a third function that clears the stack.

Listing: **stack.inc**

```
/* stack functions, part of the RPN calculator */
#include <rational>

static Rational: stack[50]
static stackidx = 0

push(Rational: value)
    {
    assert stackidx < sizeof stack
    stack[stackidx++] = value
    }

Rational: pop()
    {
    assert stackidx > 0
    return stack[--stackidx]
    }

clearstack()
    {
    assert stackidx >= 0
    if (stackidx == 0)
        return false
    stackidx = 0
    return true
    }
```

The file `stack.inc` includes the file `rational` *again*. This is technically not necessary (`rpnparse.inc` already included the definitions for rational number support), but it does not do any harm either and, for the sake of code re-use, it is better to make any file include the definitions of the libraries that it depends on.

Notice how the two global variables `stack` and `stackidx` are declared as "static" variables; using the keyword `static` instead of `new`. Doing this makes the global variables "visible" in that file only. For all other files in a larger project, the symbols `stack` and `stackidx` are invisible and they cannot (accidentally) modify the variables. It also allows the other modules to declare their own *private* variables with these names, so it avoids name clashing.

The RPN calculator is actually still a fairly small program, but it has been set up as if it were a larger program. It was also designed to demonstrate a

set of elements of the PAWN language and the example program could have been implemented more compactly.

• Event-driven programming

All of the example programs that were developed in this chapter so far, have used a "flow-driven" programming model: they start with `main` and the code determines what to do and when to request input. This programming model is easy to understand and it nicely fits most programming languages, but it is also a model does not fit many "real life" situations. Quite often, a program cannot simply process data and suggest that the user provides input only when it is ready for him/her. Instead, it is the user who decides when to provide input, and the program or script should be prepared to process it in an acceptable time, regardless of what it was doing at the moment.

The above description suggests that a program should therefore be able to interrupt its work and do other things before picking up the original task. In early implementations, this was indeed how such functionality was implemented: a multi-tasking system where one task (or thread) managed the background tasks and a second task/thread that sits in a loop continuously requesting user input. This is a heavy-weight solution, however. A more light-weight implementation of a responsive system is what is called the "event-driven" programming model.

In the event-driven programming model, a program or script decomposes any lengthy (background) task into short manageable blocks and in between, it is available for input. Instead of having the program poll for input, however, the host application (or some other sub-system) calls a function that is attached to the event —but only if the event occurs.

A typical event is "input". Observe that input does not only come from human operators. Input packets can arrive over serial cables, network stacks, internal sub-systems such as timers and clocks, and all kinds of other equipment that you may have attached to your system. Many of the apparatus that produce input, just send it. The arrival of such input is an event, just like a key press. If you do not catch the event, a few of them may be stored in an internal system queue, but once the queue is saturated the events are simply dropped.

PAWN directly supports the event-driven model, because it supports multiple entry points. The sole entry point of a flow-driven program is `main`; an

event-driven program has an entry point for every event that it captures. When compared to the flow-driven model, event-driven programs often appear "bottom-up": instead of your program calling into the host application and deciding what to do next, your program is *being called* from the outside and it is required to respond appropriately and promptly.

PAWN does not specify a standard library, and so there is no guarantee that in a particular implementation, functions like `printf` and `getvalue`. Although it is suggested that every implementation provides a minimal console/terminal interface with a these functions, their availability is ultimately implementation-dependent. The same holds for the public functions —the entry points for a script. It is implementation-dependent which public functions a host application supports. The script in this section may therefore not run on your platform (even if all previous scripts ran fine). The tools in the standard distribution of the PAWN system support all scripts developed in this manual, provided that your operating system or environment supports standard terminal functions such as setting the cursor position.

Public functions: 83

An early programming language that was developed solely for teaching the concepts of programming to children was "Logo". This dialect of LISP made programming visual by having a small robot, the "turtle", drive over the floor under control of a simple program. This concept was then copied to moving a (usually triangular) cursor of the computer display, again under control of a program. A novelty was that the turtle now left a trail behind it, allowing you to create drawings by properly programming the turtle —it became known as *turtle graphics*. The term "turtle graphics" was also used for drawing interactively with the arrow keys on the keyboard and a "turtle" for the current position. This method of drawing pictures on the computer was briefly popular before the advent of the mouse.

Listing: **turtle.p**

```
@keypressed(key)
    {
    /* get current position */
    new x, y
    wherexy x, y

    /* determine how the update the current position */
    switch (key)
        {
        case 'u': y--   /* up */
        case 'd': y++   /* down */
        case 'l': x--   /* left */
        case 'r': x++   /* right */
```

```
            case '\e': exit /* Escape = exit */
            }

        /* adjust the cursor position and draw something */
        moveturtle x, y
        }

    moveturtle(x, y)
        {
        gotoxy x, y
        print "*"
        gotoxy x, y
        }
```

The entry point of the above program is `@keypressed` —it is called on a key press. If you run the program and do not type any key, the function `@keypressed` never runs; if you type ten keys, `@keypressed` runs ten times. Contrast this behaviour with `main`: function `main` runs immediately after you start the script and it runs only once.

It is still allowed to add a `main` function to an event-driven program: the `main` function will then serve for one-time initialization. A simple addition to this example program is to add a `main` function, in order to clear the console/terminal window on entry and perhaps set the initial position of the "turtle" to the centre.

Support for function keys and other special keys (e.g. the arrow keys) is highly system-dependent. On ANSI terminals, these keys produce different codes than in a Windows "DOS box". In the spirit of keeping the example program portable, I have used common letters ("u" for *up*, "l" for *left*, etc.). This does not mean, however, that special keys are beyond PAWN's capabilities.

In the "turtle" script, the "Escape" key terminates the host application through the instruction `exit`. For a simple PAWN run-time host, this will indeed work. With host applications where the script is an add-on, or host-applications that are embedded in a device, the script usually cannot terminate the host application.

• Multiple events

The advantages of the event-driven programming model, for building reactive programs, become apparent in the presence of *multiple* events. In fact, the event-driven model is only useful if you have more that one entry point; if your script just handles a single event, it might as well enter a polling loop

for that single event. The more events need to be handled, the harder the flow-driven programming model becomes. The script below implements a bare-bones "chat" program, using only two events: one for sending and one for receiving. The script allows users on a network (or perhaps over another connection) to exchange single-line messages.

The script depends on the host application to provide the native and public functions for sending and receiving "datagrams" and for responding to keys that are typed in. *How* the host application sends its messages, over a serial line or using TCP/IP, the host application may decide itself. The tools in the standard PAWN distribution push the messages over the TCP/IP network, and allow for a "broadcast" mode so that more than two people can chat with each other.

Listing: **chat.p**

```
#include <datagram>

@receivestring(const message[], const source[])
    printf "[%s] says: %s\n", source, message

@keypressed(key)
    {
    static string[100 char]
    static index

    if (key == '\e')
        exit                    /* quit on 'Esc' key */

    echo key
    if (key == '\r' || key == '\n' || index char == sizeof string)
        {
        string{index} = '\0'    /* terminate string */
        sendstring string
        index = 0
        string[index] = '\0'
        }
    else
        string{index++} = key
    }

echo(key)
    {
    new string[2 char] = { 0 }
    string{0} = key == '\r' ? '\n' : key
    printf string
    }
```

The bulk of the above script handles gathering received key-presses into a string and sending that string after seeing the ENTER key. The "Escape" key

ends the program. The function `echo` serves to give visual feedback of what the user types: it builds a zero-terminated string from the key and prints it.

Despite its simplicity, this script has the interesting property that there is no fixed or prescribed order in which the messages are to be sent or received —there is no query–reply scheme where each host takes its turn in talking & listening. A new message may even be received while the user is typing its own message.*

• State programming

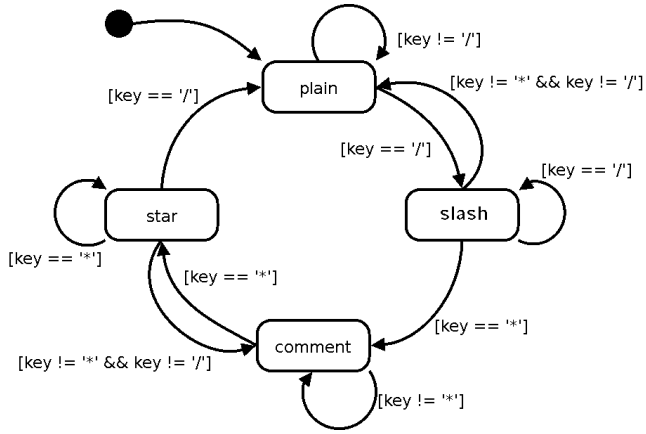
In a program following the event-driven model, events arrive individually, and they are also responded to individually. On occasion, though, an event is part of a sequential flow, that must be handled in order. Examples are data transfer protocols over, for example, a serial line. Each event may carry a command, a snippet of data that is part of a larger file, an acknowledgement, or other signals that take part in the protocol. For the stream of events (and the data packets that they carry) to make sense, the event-driven program must follow a precise hand-shaking protocol.

To adhere to a protocol, an event-driven program must respond to each event in compliance with the (recent) history of events received earlier and the responses to those events. In other words, the handling of one event may set up a "condition" or "environment" for the handling any one or more subsequent events.

A simple, but quite effective, abstraction for constructing reactive systems that need to follow (partially) sequential protocols, is that of the "automaton" or state machine. As the number of states are usually finite, the theory often refers to such automatons as *Finite State Automatons* or *Finite State Machines*. In an automaton, the context (or condition) of an event is its *state*. An event that arrives may be handled differently depending on the state of the automaton, and in response to an event, the automaton may switch to another state —this is called a *transition*. A transition, in other words, as a response of the automaton to an event in the context of its state.

* As this script makes no attempt to separate received messages from typed messages (for example, in two different scrollable regions), the terminal/console will look confusing when this happens. With an improved user-interface, this simple script could indeed be a nice message-base chat program.

Automatons are very common in software as well as in mechanical devices (you may see the Jacquard Loom as an early state machine). Automatons, with a finite number of states, are deterministic (i.e. predictable in behaviour) and their relatively simple design allows a straightforward implementation from a "state diagram".



In a state diagram, the states are usually represented as circles or rounded rectangles and the arrows represent the transitions. As transitions are the response of the automaton to events, an arrow may also be seen as an event "that does something". An event/transition that is not defined in a particular state is assumed to have no effect —it is silently ignored. A filled dot represents the entry state, which your program (or the host application) must set in start-up. It is common to omit in a state diagram all event arrows that drop back into the same state, but for the preceding figure I have chosen to make the response to all events explicit.

This state diagram is for "parsing" comments that start with "`/*`" and end with "`*/`". There are states for plain text and for text inside a comment, plus two states for *tentative* entry into or exit from a comment. The automaton is intended to parse the comments *interactively*, from characters that the user types on the keyboard. Therefore, the only events that the automaton reacts on are key presses. Actually, there is only *one* event ("key-press") and the state switches are determined by event's parameter: the *key*.

PAWN supports automatons and states directly in the language. Every function[†] may optionally have one or more states assigned to it. PAWN also

[†] With the exception of "native functions" and user-defined operators.

supports multiple automatons, and each state is part of a particular automaton. The following script implements the preceding state diagram (in a single, anonymous, automaton). To differentiate plain text from comments, both are output in a different colour.

Listing: **comment.p**

```
/* parse C comments interactively, using events and a state machine */

main()
    state plain

@keypressed(key) <plain>
    {
    state (key == '/') slash
    if (key != '/')
        echo key
    }

@keypressed(key) <slash>
    {
    state (key != '/') plain
    state (key == '*') comment
    echo '/'    /* print '/' held back from previous state */
    if (key != '/')
        echo key
    }

@keypressed(key) <comment>
    {
    echo key
    state (key == '*') star
    }

@keypressed(key) <star>
    {
    echo key
    state (key != '*') comment
    state (key == '/') plain
    }

echo(key) <plain, slash>
    printchar key, yellow

echo(key) <comment, star>
    printchar key, green

printchar(ch, colour)
    {
    setattr .foreground = colour
    printf "%c", ch
    }
```

Function `main` sets the starting state to main and exits; all logic is event-driven. When a key arrives in state `plain`, the program checks for a slash and conditionally prints the received key. The interaction between the states `plain` and `slash` demonstrates a complexity that is typical for automatons: you must decide how to respond to an event when it arrives, without being able to "peek ahead" or undo responses to earlier events. This is usually the case for event-driven systems —you neither know *what* event you will receive next, nor *when* you will receive it, and whatever your response to the current event, there is a good chance that you cannot erase it on a future event and pretend that it never happened.

In our particular case, when a slash arrives, this *might be* the start of a comment sequence ("`/*`"), but it is not necessarily so. By inference, we cannot decide on reception of the slash character what colour to print it in. Hence, we hold it back. However, there is no global variable in the script that says that a character is held back —in fact, apart from function parameters, no variable is declared at all in this script. The information about a character being held back is "hidden" in the state of the automaton.

As is apparent in the script, state changes may be conditional. The condition is optional, and you can also use the common `if`–`else` construct to change states.

Being state-dependent is not reserved for the event functions. Other functions may have state declarations as well, as the `echo` function demonstrates. When a function would have the same implementation for several states, you just need to write a single implementation and mention all applicable states. For function `echo` there are two implementations to handle the four states.*

That said, an automaton must be prepared to handle *all* events in *any* state. Typically, the automaton has neither control over *which* events arrive nor over *when* they arrive, so not handling an event in some state could lead to wrong decisions. It frequently happens, then, that a some events are meaningful only in a few specific states and that they should trigger an error or "reset" procedure in all other cases. The function for handling the event in such "error" condition might then hold a lot of state names, if you were to mention them explicitly. There is a shorter way: by not mentioning

* A function that has the same implementation for *all* states, does not need a state classifierat all —see `printchar`.

FIGURE 1: *Pedestrian crossing lights*

any name between the angle brackets, the function matches *all* states that have not explicit implementation elsewhere. So, for example, you could use the signature "`echo(key) <>`" for either of the two implementations (but not for both).

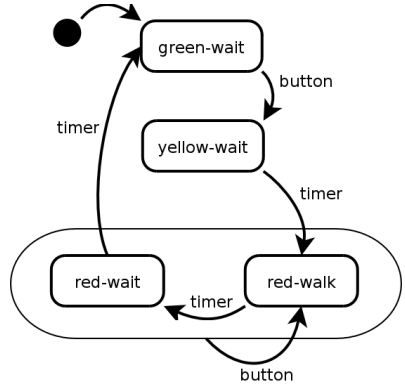
A single anonymous automaton is pre-defined. If a program contains more than one automaton, the others must be explicitly mentioned, both in the state classifier of the function and in the `state` instruction. To do so, add the name of the automaton in front of the state name and separate the names of the automaton and the state with a colon. That is, "`parser:slash`" stands for the state `slash` of the automaton `parser`. A function can only be part of a single automaton; you can share one implementation of a function for several states of *the same* automaton, but you cannot share that function for states of *different* automatons.

• Entry functions and automata theory

State machines, and the foundation of "automata theory", originate from mechanical design and pneumatic/electric switching circuits (using relays rather than transistors). Typical examples are coin acceptors, traffic light control and communication switching circuits. In these applications, robustness and predictability are paramount, and it was found that these goals were best achieved when actions (output) were tied to the *states* rather than to the *events* (input). In this design, entering a state causes activity —events cause state changes, but do not carry out other operations.

In a pedestrian crossing lights system, the lights for the vehicles and the

pedestrians must be synchronized. Technically, there are six possible combinations, but obviously the combination of a green light for the traffic and a "walk" sign for the pedestrians is recipe for disaster. We can also immediately dismiss the combination of *yellow/walk* as too dangerous. Thus, four combinations remain to be handled. The figure below is a state diagram for the pedestrian crossing lights. The entire process is activated with a button, and operates on a timer.



When the state *red/walk* times out, the state cannot immediately go back to *green/wait*, because the pedestrians that are busy crossing the road at that moment need some time to clear the road —the state *red/wait* allows for this. For purpose of demonstration, this pedestrian crossing has the added functionality that when a pedestrian pushes the button while the light for the traffic is already red, the time that the pedestrian has for crossing is lengthened. If the state is *red/wait* and the button is pressed, it switches back to *red/walk*. The enfolding box around the states *red/walk* and *red/wait* for handling the button event is just a notational convenience: I could also have drawn two arrows from either state back to *red/walk*. The script source code (which follows below) reflects this same notational convenience, though.

In the implementation in the PAWN language, the event functions now always have a single statement, which is either a state change or an empty statement. Events that do not cause a state change are absent in the diagram, but they *must* be handled in the script; hence, the "fall-back" event functions that do nothing. The output, in this example program only messages printed on the console, is all done in the special functions `entry`. The function `entry` may be seen as a `main` for a state: it is implicitly called when the state that it is attached to is entered. Note that the `entry` function is also called when

"switching" to the state that the automaton is already in: when the state is `red_walk` an invocation of the `@keypressed` sets the state to `red_walk` (which it is already in) and causes the `entry` function of `red_walk` to run —this is a re-entry of the state.

Listing: **traffic.p**

```
/* traffic light synchronizer, using states in an event-driven model */
#include <time>

main()                                  state green_wait

@keypressed(key) <green_wait>           state yellow_wait
@keypressed(key) <red_walk, red_wait>   state red_walk
@keypressed(key) <>                     {} /* fallback */

@timer()         <yellow_wait>          state red_walk
@timer()         <red_walk>             state red_wait
@timer()         <red_wait>             state green_wait
@timer()         <>                     {} /* fallback */


entry() <green_wait>
    print "Green / Don't walk\n"

entry() <yellow_wait>
    {
    print "Yellow / Don't walk\n"
    settimer 2000
    }

entry() <red_walk>
    {
    print "Red / Walk\n"
    settimer 5000
    }

entry() <red_wait>
    {
    print "Red / Don't walk\n"
    settimer 2000
    }
```

This example program has an additional dependency on the host application/environment: in addition to the "`@keypressed`" event function, the host must also provide an adjustable "`@timer`" event. Because of the timing functions, the script includes the system file `time.inc` near the top of the script.

The event functions with the state changes are all on the top part of the script. The functions are laid out to take a single line each, to suggest a table-like structure. All state changes are unconditional in this example,

but conditional state changes may be used with `entry` functions too. The bottom part are the event functions.

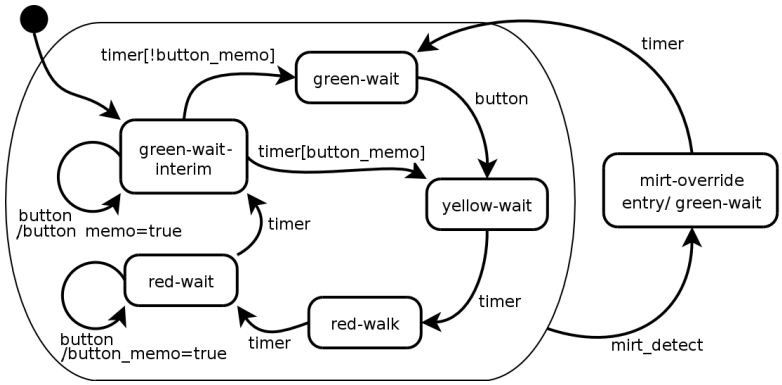
Two transitions to the state `red_walk` exist —or three if you consider the affection of multiple states to a single event function as a mere notational convenience: from `yellow_wait` and from the combination of `red_walk` and `red_wait`. These transitions all pass through the same `entry` function, thereby reducing and simplifying the code.

In automata theory, an automaton that associates activity with state entries, such as this pedestrian traffic lights example, is a "Moore automaton"; an automaton that associates activity with (state-dependent) events or transitions is a "Mealy automaton". The interactive comment parser on page 39 is a typical Mealy automaton. The two kinds are equivalent: a Mealy automaton can be converted to a Moore automaton and vice versa, although a Moore automaton may need more states to implement the same behaviour. In practice, the models are often *mixed*, with an overall "Moore automaton" design, and a few "Mealy states" where that saves a state.

• State variables

The model of a pedestrian crossing light in the previous example is not very realistic (its only goal is to demonstrate a few properties of state programming with PAWN). The first thing that is lacking is a degree of *fairness*: pedestrians should not be able to block car traffic indefinitely. The car traffic should see a green light for a period of some minimum duration after pedestrians have had their time slot for crossing the road. Secondly, many traffic lights have a kind of remote control ability, so that emergency traffic (ambulance, fire truck, ...) can force green lights on their path. A well-known example of such remote control is the MIRT system (Mobile Infra-Red Transmitter) but other systems exist —the Netherlands use a radiographic system called VETAG for instance.

The new state diagram for the pedestrian crossing light has two more states, but more importantly: it needs to save data across events and share it between states. When the pedestrian presses the button while the state is `red_wait`, we neither want to react on the button immediately (this was our "fairness rule"), nor the button to be ignored or "forgotten". In other words, we move to the state `green_wait_interim` regardless of the button press, but memorize the press for a decision made at the point of leaving state `green_wait_interim`.



Automatons excel in modelling control flow in reactive/interactive systems, but data flow has traditionally been a weak point. To see why, consider that each event is handled individually by a function and that the local variables in that function disappear when the function returns. Local variables can, hence, not be used to pass data from one event to the next. Global variables, while providing a work-around, have drawbacks: global scope and an "eternal" lifespan. If a variable is used only in the event handlers of a single state, it is desirable to hide it from the other states, in order to protect it from accidental modification. Likewise, shortening the lifespan to the state(s) that the variable is active in, reduces the memory footprint. "State variables" provide this mix of variable scope and variable lifespan that are tied to a series of states, rather than to functions or modules.

PAWN enriches the standard *finite state machine* (or automaton) with variables that are declared with a state classifier. These variables are only accessible from the listed states and the memory these variable hold may be reused by other purposes while the automaton is in a different state (different than the ones listed). Apart from the state classifier, the declaration of a state variable is similar to that of a global variable. The declaration of the variable `button_memo` in the next listing illustrates the concept.

To reset the memorized button press, the script uses an "`exit`" function. Just like an `entry` function is called when entering a state, the `exit` function is called when leaving a state.

Listing: **traffic2.p**

```
/* a more realistic traffic light synchronizer, including an
 * "override" for emergency vehicles
 */
#include <time>
```

```
main()
    state green_wait_interim

new bool: button_memo <red_wait, green_wait_interim>

@keypressed(key)
    {
    switch (key)
        {
        case ' ': button_press
        case '*': mirt_detect
        }
    }

button_press() <green_wait>
    state yellow_wait

button_press() <red_wait, green_wait_interim>
    button_memo = true

button_press() <>               /* fallback */
    {}

mirt_detect()
    state mirt_override

@timer() <yellow_wait>
    state red_walk

@timer() <red_walk>
    state red_wait

@timer() <red_wait>
    state green_wait_interim

@timer() <green_wait_interim>
    {
    state (!button_memo) green_wait
    state (button_memo) yellow_wait
    }

@timer() <mirt_override>
    state green_wait

@timer() <>                     /* fallback */
    {}


entry() <green_wait_interim>
    {
    print "Green / Don't walk\n"
    settimer 5000
    }

exit() <green_wait_interim>
    button_memo = false
```

```
entry() <yellow_wait>
    {
    print "Yellow / Don't walk\n"
    settimer 2000
    }

entry() <red_walk>
    {
    print "Red / Walk\n"
    settimer 5000
    }

entry() <red_wait>
    {
    print "Red / Don't walk\n"
    settimer 2000
    }

entry() <mirt_override>
    {
    print "Green / Don't walk\n"
    settimer 5000
    }
```

• State programming wrap-up

The common notation used in state diagrams is to indicate transitions with arrows and states with circles or rounded rectangles. The circle/rounded rectangle optionally also mentions the actions of an `entry` or `exit` function and of events that are handled internally —without causing a transition. The arrow for a transition contains the name of the event (or pseudo-event), an optional condition between square brackets and an optional action behind a slash ("/").

States are ubiquitous, even if we do not always recognize them as such. The concept of finite state machines has traditionally been applied mostly to programs mimicking mechanical apparatus and software that implements communication protocols. With the appearance of event-driven windowing systems, state machines now also appear in the GUI design of desktop programs. States abound in web programs, because the browser and the web-site scripting host have only a weak link. That said, the state machine in web applications is typically implemented in an ad-hoc manner.

States can also be recognized in common problems and riddles. In the well known riddle of the man that must move a cabbage, a sheep and a wolf

across a river,* the states are obvious —the trick of the riddle is to avoid the *forbidden* states.

But now that we are discovering "states" everywhere, we must be careful not to overdo it. For example, in the second implementation of a pedestrian crossing light, see page 45, I used a variable (`button_memo`) to hold a criterion for a decision made at a later time. An alternative implementation would be to throw in a couple of more states to hold the situations "red-wait-&-button-pressed" and "green-wait-interim-&-button-pressed". No more variable would then be needed, but at the cost of a more complex state diagram and implementation. In general, the number of states should be kept small.

Although automata provide a good abstraction to model reactive and interactive systems, coming to a correct diagram is not straightforward —and sometimes just outright hard. Too often, the "sunny day scenario" of states and events is plotted out first, and everything straying from this path is then added on an impromptu basis. This approach carries the risk that some combinations of events & states are forgotten, and indeed I have encountered two comment parser diagrams (like the one at page 39) by different book/magazine authors that were flawed in such way. Instead, I advise to focus on the events and on the responses for individual events. For every state, every event should be considered; do not route events through a general purpose fall-back too eagerly.

It has become common practice, unfortunately, to introduce automata theory with applications for which better solutions exist. One, oft repeated, example is that of an automaton that accumulates the value of a series of coins, or that "calculates" the remainder after division by 3 of a binary number. These applications may have made sense in mechanical/pneumatic design where "the state" is the only memory that the automaton has, but in software, using variables and arithmetic operations is *the better choice*. Another typical example is that of matching words or patterns using a state machine: every next letter that is input switches to a new state. Lexical *scanners*, such as the ones that compilers and interpreters use to interpret source code, might use such state machines to filter out "reserved words". However, for any practical set of reserved words, such automatons become

* A man has to ferry a wolf, a sheep and a cabbage across a river in a boat, but the boat can only carry the man and a single additional item. If left unguarded, the wolf will eat the sheep and the sheep will eat the cabbage. How can the man ferry them across the river?

unwieldy, and no one will design them by hand. In addition, there is no reason why a lexical scanner cannot peek ahead in the text or jump back to a mark that it set earlier —which is one of the criteria for choosing a state implementation in the first place, and finally, solutions like trie lookups are likely simpler to design and implement while being at least as quick.

• Program verification

Should the compiler/interpreter not catch all bugs? This rhetorical question has both technical and philosophical sides. I will forego all non-technical aspects and only mention that, in practice, there is a trade-off between the "expressiveness" of a computer language and the "enforced correctness" (or "provable correctness') of programs in that language. Making a language very "strict" is not a solution if work needs to be done that exceeds the size of a toy program. A too strict language leaves the programmer struggling with the language, whereas the "problem to solve" should be the *real* struggle and the language should be a simple means to express the solution in.

The goal of the PAWN language is to provide the developer with an informal, and convenient to use, mechanism to test whether the program behaves as was intended. This mechanism is called "assertions" and, although the concept of assertions pre-dates the idea of "design by contract", it is most easily explained through the design-by-contract methodology.

The "design by contract" paradigm provides an alternative approach for dealing with erroneous conditions. The premise is that the programmer knows the task at hand, the conditions under which the software must operate and the environment. In such an environment, each function specifies the specific conditions, in the form of *assertions*, that must hold true before a client may execute the function. In addition, the function may also specify any conditions that hold true after it completes its operation. This is the "contract" of the function.

The name "design by contract" was coined by Bertrand Meyer and its principles trace back to predicate logic and algorithmic analysis.

◇ Preconditions specify the valid values of the input parameters and environmental attributes;

◇ Postconditions specify the output and the (possibly modified) environment;

◇ Invariants indicate the conditions that must hold true at key points in a function, regardless of the path taken through the function.

Example square root function (using bisection): 79

For example, a function that computes a square root of a number may specify that its input parameter be non-negative. This is a precondition. It may also specify that its output, when squared, is the input value ±0.01%. This is a postcondition; it verifies that the routine operated correctly. A convenient way to calculate a square root is via "bisection". At each iteration, this algorithm gives at least one extra *bit* (binary digit) of accuracy. This is an invariant (it might be an invariant that is hard to check, though).

Preconditions, postconditions and invariants are similar in the sense that they all consist of a test and that a failed test indicates an error in the implementation. As a result, you can implement preconditions, postconditions and invariants with a single construct: the "assertion". For preconditions, write assertions at the very start of the routine; for invariants, write an assertion where the invariant should hold; for post conditions, write an assertion before each "return" statement or at the end of the function.

In PAWN, the instruction is called `assert`; it is a simple statement that contains a test. If the test outcome is "true", nothing happens. If the outcome is "false", the assert instruction terminates the program with a message containing the details of the assertion that failed.

Assertions are checks that should never fail. Genuine errors, such as user input errors, should be handled with explicit tests in the program, and *not* with assertions. As a rule, the expressions contained in assertions should be free of side effects: an assertion should never contain code that your application requires for correct operation.

This does have the effect, however, that assertions never fire in a bug-free program: they just make the code *fatter* and *slower*, without any user-visible benefit. It is not this bad, though. An additional feature of assertions is that you can build the source code *without assertions* simply using a flag or option to the PAWN parser. The idea is that you enable assertions during development and build the "retail version" of the code without assertions. This is a better approach than removing the assertions, because all assertions are automatically "back" when recompiling the program —e.g. for maintenance.

During maintenance, or even during the initial development, if you catch a bug that was not trapped by an assertion, before fixing the bug, you should think of how an assertion could have trapped this error. Then, add this

assertion and test whether it indeed catches the bug *before* fixing the bug. By doing this, the code will gradually become sturdier and more reliable.

• Documentation comments

When programs become larger, documenting the program and the functions becomes vital for its maintenance, especially when working in a team. The PAWN language tools have some features to assist you in documenting the code in comments. Documenting a program or library in its comments has a few advantages —for example: documentation is more easily kept up to date with the program, it is efficient in the sense that programming comments now double as documentation, and the parser helps your documentation efforts in generating syntax descriptions and cross references.

Every comment that starts with three slashes ("`///` ") followed by white-space, or that starts with a slash and two stars ("`/**` ") followed by white-space is a special *documentation* comment. The PAWN compiler extracts documentation comments and optionally writes these to a "report" file. See the application documentation, or appendix B, how to enable the report generation.

Comment syntax: 97

As an aside, comments that start with "`/**`" must still be closed with "`*/`". Single line documentation comments ("`///`") close at the end of the line.

The report file is an XML file that can subsequently be transformed to HTML documentation via an XSL/XSLT stylesheet, or be run through other tools to create printed documentation. The syntax of the report file is compatible with that of the ".Net" developer products —except that the PAWN compiler stores more information in the report than just the extracted documentation strings. The report file contains a reference to the "SMALLDOC.XSL" stylesheet.

The example below illustrates documentation comments in a simple script that has a few functions. You may write documentation comments for a function above its declaration or in its body. All documentation comments that appear before the end of the function are attributed to the function. You can also add documentation comments to global variables and global constants —these comments must appear above the declaration of the variable or constant. Figure 2 shows part of the output for this (rather long) example. The style of the output is adjustable in the cascading style sheet (CSS-file) associated with the XSLT transformation file.

Listing: **weekday.p**

```
/**
 * This program illustrates Zeller's congruence algorithm to calculate
 * the day of the week given a date.
 */

/**
 *  <summary>
 *    The main program: asks the user to input a date and prints on
 *    what day of the week that date falls.
 *  </summary>
 */
main()
    {
    new day, month, year
    if (readdate(day, month, year))
        {
        new wkday = weekday(day, month, year)
        printf "The date %d-%d-%d falls on a ", day, month, year
        switch (wkday)
            {
            case 0:
                print "Saturday"
            case 1:
                print "Sunday"
            case 2:
                print "Monday"
            case 3:
                print "Tuesday"
            case 4:
                print "Wednesday"
            case 5:
                print "Thursday"
            case 6:
                print "Friday"
            }
        }
    else
        print "Invalid date"

    print "\n"
    }

/**
 * <summary>
 *   The core function of Zeller's congruence algorithm. The function
 *   works for the Gregorian calender.
 * </summary>
 *
 * <param name="day">
 *   The day in the month, a value between 1 and 31.
 * </param>
 * <param name="month">
```

```
 *   The month: a value between 1 and 12.
 * </param>
 * <param name="year">
 *   The year in four digits.
 * </param>
 *
 * <returns>
 *   The day of the week, where 0 is Saturday and 6 is Friday.
 * </returns>
 *
 * <remarks>
 *   This function does not check the validity of the date; when the
 *   date in the parameters is invalid, the returned "day of the week"
 *   will hold an incorrect value.
 *   <p/>
 *   This equation fails in many programming languages, notably most
 *   implementations of C, C++ and Pascal, because these languages have
 *   a loosely defined "remainder" operator. Pawn, on the other hand,
 *   provides the true modulus operator, as defined in mathematical
 *   theory and as was intended by Zeller.
 * </remarks>
 */
weekday(day, month, year)
    {
    /**
     * <remarks>
     *   For Zeller's congruence algorithm, the months January and
     *   February are the 13th and 14th month of the <em>preceding</em>
     *   year. The idea is that the "difficult month" February (which
     *   has either 28 or 29 days) is moved to the end of the year.
     * </remarks>
     */
    if (month <= 2)
        month += 12, --year

    new j = year % 100
    new e = year / 100
    return (day + (month+1)*26/10 + j + j/4 + e/4 - 2*e) % 7
    }

/**
 * <summary>
 *   Reads a date and stores it in three separate fields. tata
 * </summary>
 *
 * <param name="day">
 *   Will hold the day number upon return.
 * </param>
 * <param name="month">
 *   Will hold the month number upon return.
 * </param>
 * <param name="year">
```

```
 *   Will hold the year number upon return.
 * </param>
 *
 * <returns>
 *   <em>true</em> if the date is valid, <em>false</em> otherwise;
 *   if the function returns <em>false</em>, the values of
 *   <paramref name="day"/>, <paramref name="month"/> and
 *   <paramref name="year"/> cannot be relied upon.
 * </returns>
 */
bool: readdate(&day, &month, &year)
    {
    print "Give a date (dd-mm-yyyy): "
    day = getvalue(_,'-','/')
    month = getvalue(_,'-','/')
    year = getvalue()
    return 1 <= month <= 12 && 1 <= day <= daysinmonth(month,year)
    }

/**
 * <summary>
 *   Returns whether a year is a leap year.
 * </summary>
 *
 * <param name="year">
 *   The year in 4 digits.
 * </param>
 *
 * <remarks>
 *   A year is a leap year:
 *   <ul>
 *     <li> if it is divisable by 4, </li>
 *     <li> but <strong>not</strong> if it is divisable by 100, </li>
 *     <li> but it <strong>is</strong> it is divisable by 400. </li>
 *   </ul>
 * </remarks>
 */
bool: isleapyear(year)
    return year % 400 == 0 || year % 100 != 0 && year % 4 == 0

/**
 * <summary>
 *   Returns the number of days in a month (the month is an integer
 *   in the range 1 .. 12). One needs to pass in the year as well,
 *   because the function takes leap years into account.
 * </summary>
 *
 * <param name="month">
 *   The month number, a value between 1 and 12.
 * </param>
 * <param name="year">
 *   The year in 4 digits.
```

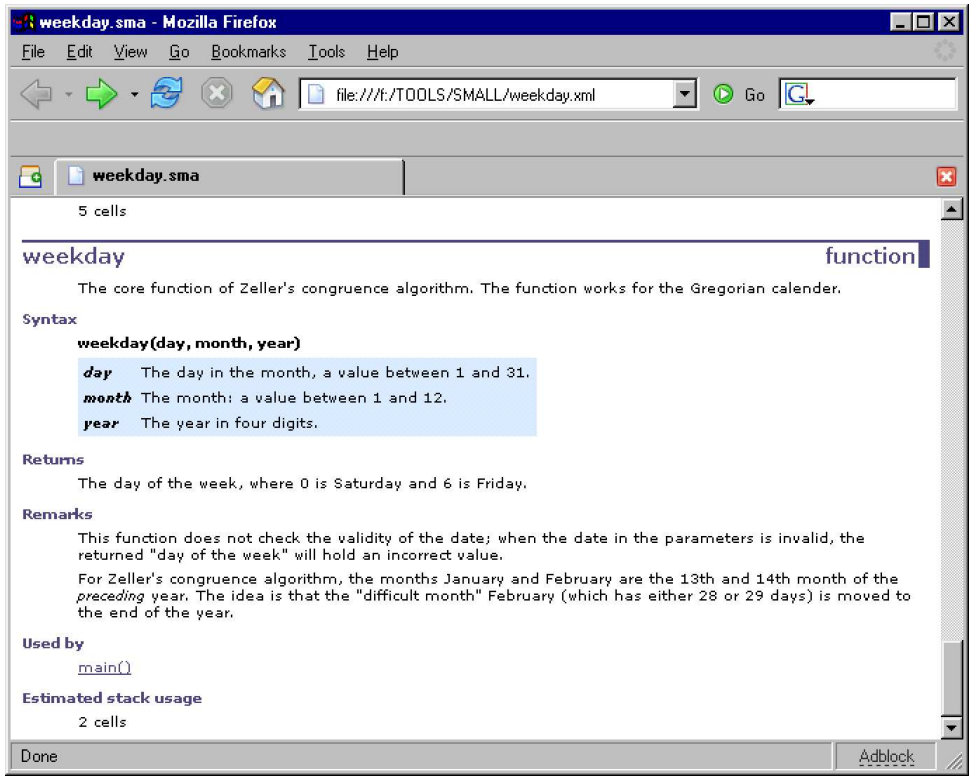


FIGURE 2: *Documentation generated from the source code*

```
 * </param>
 */
daysinmonth(month, year)
    {
    static daylist[] = {31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31}
    assert 1 <= month <= 12
    return daylist[month-1] + _:(month == 2 && isleapyear(year))
    }
```

The format of the XML file created by ".Net" developer products is documented in the Microsoft documentation. The PAWN parser creates a minimal description of each function or global variable or constant that is *used* in a project, regardless of whether you used documentation comments on that function/variable/constant. The parser also generates few tags of its own:

attribute Attributes for a function, such as "native" or "stock".

automaton — The automaton that the function belongs to (if any).

dependency — The names of the symbols (other functions, global variables and/global constants) that the function requires. If desired, a call tree can be constructed from the dependencies.

param — Function parameters. When you add a parameter description in a documentation comment, this description is combined with the auto-generated content for the parameter.

paraminfo — Tags and array or reference information on a parameter.

referrer — All functions that refer to this symbol; i.e., all functions that use or call this variable/function. This information is sufficient to serve as a "cross-reference" —the "referrer" tree is the inverse of the "dependency" tree.

stacksize — The estimated number of cells that the function will allocate on the stack and heap. This stack usage estimate *excludes* the stack requirements of any functions that are "called" from the function to which the documentation applies. For example, function `readdate` is documented as taking 6 cells on the stack, but it also calls `daysinmonth` which takes 4 additional cells — and in turn calls `isleapyear`. To calculate the total stack requirements for function `readdate`, the call tree should be considered.

In addition to the local variables and function parameters, the compiler also uses the stack for storing intermediate results in complex expressions. The stack space needed for these intermediate results are also *excluded* from this report. In general, the required overhead for the intermediate results is not cumulative (over all functions), which is why it would be inaccurate to add a "safety margin" to every function. For the program as a whole, a safety margin would be highly advised. See appendix B (page 169) for the `-v` option which can tell you the maximum estimate stack usage, based on the call tree.

tagname — The tag of the constant, variable, function result or function parameter(s).

transition — The transitions that the function provokes and their conditions —see the section of automatons on page 37.

All text in the documentation comment(s) is also copied to each function, variable or constant to which it is attached. The text in the documentation comment is copied without further processing —with one exception, see below. As the rest of the report file is in XML format, and the most suitable way to process XML to on-line documentation is through an XSLT processor (such as a modern browser), you may choose to do any formatting in the documentation comments using HTML tags. Note that you will often need to explicitly close any HTML tags; the HTML standard does not require this, but XML/XSLT processors usually do. The PAWN toolkit comes with an example XSLT file (with a matching style sheet) which supports the following XML/HTML tags:

`<code> </code>`	Formatted source code in a monospaced font; although the "`&`", "`<`" and "`>`" must be typed as "&", "<" and "&rt;" respectively.
`<example> </example>`	Text set under the topic "Example".
`<param name="..."> </param>`	A parameter description, with the parameter name appearing inside the opening tag (the "`name=`" option) and the parameter description following it.
`<paramref name="..." />`	A reference to a parameter, with the parameter name appearing inside the opening tag (the "`name=`" option).
`<remarks> </remarks>`	Text set under the topic "Remarks".
`<returns> </returns>`	Text set under the topic "Returns".
`<seealso> </seealso>`	Text set under the topic "See also".
`<summary> </summary>`	Text set immediately below the header of the symbol.
`<section> </section>`	Sets the text in a header. This should only be used in documentation that is not attached to a function or a variable.
`<subsection> </subsection>`	Sets the text in a sub-header. This should only be used in documentation that is not attached to a function or a variable.

The following additional HTML tags are supported for general purpose formatting text inside any of the above sections:

`<c> </c>`	Text set in a monospaced font.
`<em> </em>`	Text set emphasized, usually in italics.

`<p> </p>`	Text set in a new paragraph. Instead of wrapping `<p>` and `</p>` around every paragraph, inserting `<p/>` as a separator between two paragraphs produces the same effect.
`<para> </para>`	An alternative for `<p> </p>`
`<ul> </ul>`	An unordered (bulleted) list.
`<ol> </ol>`	An ordered (numbered) list.
`<li> </li>`	An item in an ordered or unordered list.

As stated, there is one exception in the processing of documentation comments: if your documentation comment contains a `<param ...>` tag (and a matching `</param>`), the PAWN parser looks up the parameter and combines your description of the parameter with the contents that it has automatically generated.

• Warnings and errors

The big hurdle that I have stepped over is how to actually compile the code snippets presented in this chapter. The reason is that the procedure depends on the system that you are using: in some applications there is a "Make" or "Compile script" command button or menu option, while in other environments you have to type a command like "`pawncc myscript`" on a command prompt. If you are using the standard PAWN toolset, you will find instructions of how to use the compiler and run-time in the companion booklet "The PAWN booklet — Implementer's Guide". If you are using Microsoft Windows, it may prove the most convenient to use the Quincy IDE that comes with PAWN for writing, running and debugging scripts.

Regardless of the differences in launching the compile, the phenomenon that results from launching the compile are likely to be very similar between all systems:

- ◇ either the compile succeeds and produces an executable program —that may or may not run automatically after the compile;
- ◇ or the compile gives a list of warning and error messages.

Mistakes happen and the PAWN parser tries to catch as many of them as it can. When you inspect the code that the PAWN parser complains about, it may on occasion be rather difficult for you to see why the code is erroneous (or suspicious). The following hints may help:

- ◇ Each error or warning number is numbered. You can look up the error message with this number in appendix A, along with a brief description on what the message really means.
- ◇ If the PAWN parser produces a list of errors, the *first* error in this list is a true error, but the diagnostic messages below it may not be errors at all.

  After the PAWN parser sees an error, it tries to step over it and complete the compilation. However, the stumbling on the error may have confused the PAWN parser so that subsequent legitimate statements are misinterpreted and reported as errors too.

  When in doubt, fix the first error and recompile.
- ◇ The PAWN parser checks only the syntax (spelling/grammar), not the semantics (i.e. the "meaning") of the code. When it detects code that does not comply to the syntactical rules, there may actually be different ways in which the code can be changed to be "correct", in the syntactical sense of the word —even though many of these "corrections" would lead to nonsensical code. The result is, though, that the PAWN parser may have difficulty to precisely locate the error: it does not know what you meant to write. Hence, the parser often outputs two line numbers and the error is somewhere in the range (between the line numbers).
- ◇ Remember that a program that has no syntactical errors (the PAWN parser accepts it without error & warning messages) may still have semantical and logical errors which the PAWN parser cannot catch. The `assert` instruction (page 113) is meant to help you catch these "run-time" errors.

• In closing

If you know the C programming language, you will have seen many concepts that you are familiar with, and a few new ones. If you don't know C, the pace of this introduction has probably been quite high. Whether you are new to C or experienced in C, I encourage you to read the following pages carefully. If you know C or a C-like language, by the way, you may want to consult the chapter "Pitfalls" (page 134) first.

This booklet attempts to be both an informal introduction and a (more formal) language specification at the same time, perhaps succeeding at neither. Since it is also the *standard* book on PAWN,* the focus of this booklet is on

* It is no longer the *only* book on Pawn.

being accurate and complete, rather than being easy to grasp.

The double nature of this booklet shows through in the order in which it presents the subjects. The larger conceptual parts of the language, variables and functions, are covered first. The operators, the statements and general syntax rules follow later —not that they are less important, but they are easier to learn, to look up, or to take for granted.

Data and declarations

PAWN is a typeless language. All data elements are of type "cell", and a cell can hold an integral number. The size of a cell (in bytes) is system dependent —usually, a cell is 32-bits.

The keyword `new` declares a new variable. For special declarations, the keyword `new` is replaced by `static`, `public` or `stock` (see below). A simple variable declaration creates a variable that occupies one "cell" of data memory. Unless it is explicitly initialized, the value of the new variable is zero.

A variable declaration may occur:

- ◇ at any position where a statement would be valid —local variables;
- ◇ at any position where a function declaration (native function declarations) or a function implementation would be valid —global variables;
- ◇ in the first expression of a `for` loop instruction —also local variables.

"for" loop: 114

Local declarations

A local declaration appears inside a compound statement. A local variable can only be accessed from within the compound statement, and from nested compound statements. A declaration in the first expression of a `for` loop instruction is also a local declaration.

Compound statement: 113

Global declarations

A global declaration appears outside a function and a global variable is accessible to any function. Global data objects can only be initialized with constant expressions.

• State variable declarations

A state variable is a global variable with a state classifier appended at the end. The scope and the lifespan of the variable are restricted to the states that are listed in the classifier. Fall-back state specifiers are not permitted for state variables.

State variables may not be initialized. In contrast to normal variables (which are zero after declaration —unless explicitly initialized), state variables hold an indeterminate value after declaration and after first entering a state in its classifier. Typically, one uses the state `entry` function(s) to properly initialize the state variable, and the `exit` function(s) to reset these variables.

• Static local declarations

A local variable is destroyed when the execution leaves the compound block in which the variable was created. Local variables in a function only exist during the run time of that function. Each new run of the function creates and initializes new local variables. When a local variable is declared with the keyword `static` rather than `new`, the variable remains in existence after the end of a function. This means that static local variables provide private, permanent storage that is accessible only from a single function (or compound block). Like global variables, static local variables can only be initialized with constant expressions.

• Static global declarations

A static global variable behaves the same as a normal global variable, except that its scope is restricted to the file that the declaration resides in. To declare a global variable as static, replace the keyword `new` by `static`.

• Stock declarations

Stock functions: 84

A global variable may be declared as "stock". A stock declaration is one that the parser may remove or ignore if the variable turns out not to be used in the program.

Stock variables are useful in combination with stock functions. A public variable may be declared as "stock" as well —declaring public variables as "public stock" enables you to declare al public variables that a host application provides in an include file, with only those variables that the script actually uses winding up in the P-code file.

• Public declarations

Global "simple" variables (no arrays) may be declared "public" in two ways:
◇ declare the variable using the keyword `public` instead of `new`;
◇ start the variable name with the "@" symbol.

Public variables behave like global variables, with the addition that the host program can also read and write public variables. A (normal) global variable can only be accessed by the functions in your script —the host program is unaware of them. As such, a host program may require that you declare a

variable with a specific name as "public" for special purposes —such as the most recent error number, or the general program state.

• Constant variables

It is sometimes convenient to be able to create a variable that is initialized once and that may not be modified. Such a variable behaves much like a symbolic constant, but it still is a variable.

Symbolic constants: 102

To declare a constant variable, insert the keyword `const` between the keyword that starts the variable declaration —`new`, `static`, `public` or `stock`— and the variable name.

Examples:

```
new const address[4] = { 192, 0, 168, 66 }
public const status              /* initialized to zero */
```

Three typical situations where one may use a constant variable are:

- ◇ To create an "array" constant; symbolic constants cannot be indexed.
- ◇ For a public variable that should be set by the host application, and *only* by the host application. See the preceding section for public variables.
- ◇ A special case is to mark array arguments to functions as `const`. Array arguments are always passed by reference, declaring them as `const` guards against unintentional modification. Refer to page 72 for an example of `const` function arguments.

• Arrays (single dimension)

The syntax `name[constant]` declares `name` to be an array of "`constant`" elements, where each element is a single cell. The `name` is a placeholder of an identifier name of your choosing and `constant` is a positive non-zero value; `constant` may be absent. If there is no value between the brackets, the number of elements is set equal to the number of initiallers —see the example below.

See also "multi-dimensional arrays", page 65

The array index range is "zero based" which means that the first element is at `name[0]` and the last element is `name[constant-1]`.

• Initialization

Constants: 98

Data objects can be initialized at their declaration. The initialler of a global data object must be a constant. Arrays, global or local, must also be initialized with constants.

Uninitialized data defaults to zero.

Examples:

Listing: **good declaration**

```
new i = 1
new j                          /* j is zero */
new k = 'a'                    /* k has character code for letter 'a' */

new a[] = {1,4,9,16,25}        /* a has 5 elements */
new s1[20] = {'a','b'}         /* the other 18 elements are 0 */

new s2[] = "Hello world..."    /* a unpacked string */
```

Examples of **invalid** declarations:

Listing: **bad declarations**

```
new c[3] = 4                   /* an array cannot be set to a value */
new i = "Good-bye"             /* only an array can hold a string */
new q[]                        /* unknown size of array */
new p[2] = { i + j, k - 3 }    /* array initiallers must be constants */
```

• Progressive initiallers for arrays

The ellipsis operator continues the progression of the initialisation constants for an array, based on the last two initialized elements. The ellipsis operator (three dots, or "...") initializes the array up to its declared size.

Examples:

Listing: **array initializers**

```
new a[10] = { 1, ... }            // sets all ten elements to 1
new b[10] = { 1, 2, ... }         // b = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10
new c[8] = { 1, 2, 40, 50, ... }  // c = 1, 2, 40, 50, 60, 70, 80, 90
new d[10] = { 10, 9, ... }        // d = 10, 9, 8, 7, 6, 5, 4, 3, 2, 1
```

• array initialization and enumerations

The array size may be set with a constant that represents an enumeration: an example of this is the "priority queue" sample program at page 19. When individual fields of the enumeration have a size, the associated array elements are interpreted as *sub-arrays*, on occasion. For an example of this behaviour, see the RPN calculator program at page 28.

The sub-array syntax applies as well to the initialization of an "enumerated" array. Referring again to the "priority queue" sample program, to initialize a "message" array with fixed values, the syntax is:

Listing: **array initializers**

```
enum message        /* declaration copied from "QUEUE.P" */
    {
    text[40 char],
    priority
    }

new msg[message] = { !"new message", 1 }
```

The initialler consists of a string (a literal array) and a value; these go into the fields "`text`" and "`priority`" respectively.

• Multi-dimensional arrays

Multi-dimensional arrays are arrays that contain references to the sub-arrays. That is, a two-dimensional array is an "array of single-dimensional arrays".* Below are a few examples of declarations of two-dimensional arrays.

Listing: **Two-dimensional arrays**

```
new a[4][3]
new b[3][2] = { { 1, 2 }, { 3, 4 }, { 5, 6 } }
new c[3][3] = { { 1 }, { 2, ...}, { 3, 4, ... } }
new d[2][5] = { !"agreement", !"dispute" }
new e[2][]  = { "OK", "Cancel" }
new f[][]   = { "OK", "Cancel" }
```

* The current implementation of the Pawn compiler supports only arrays with up to three dimensions.

As the last two declarations (variable "e" en "f") show, the final dimension of an array may have an unspecified length, in which case the length of each sub-array is determined from the related initializer. Every sub-array may have a different size; in this particular example, "e[1][5]" contains the letter "l" from the word "Cancel", but "e[0][5]" is *invalid* because the length of the sub-array "e[0]" is only three cells (containing the letters "O", "K" and a zero terminator).

The difference between the declarations for arrays "e" and "f" is that in we let the compiler count the number of initializers for the major dimension —"sizeof f" is 2, like "sizeof e" (see the next section on the sizeof operator).

• Arrays and the sizeof operator

The sizeof operator returns the size of a variable in "elements". For a simple (non-compound) variable, the result of sizeof is always 1, because an element is a cell for a simple variable.

An array with one dimension holds a number of cells and the sizeof operator returns that number. The snippet below would therefore print "5" at the display, because the array "msg" holds four characters (each in one cell) plus a zero-terminator:

Listing: **sizeof operator**

```
new msg[] = "Help"
printf("%d", sizeof msg);
```

With multi-dimensional arrays, the sizeof operator can return the number of elements in each dimension. For the last (minor) dimension, an element will again be a cell, but for the major dimension(s), an element is a sub-array. In the following code snippet, observe that the syntax sizeof matrix refers to the major dimension of the two-dimensional array and the syntax sizeof matrix[] refers to the minor dimension of the array. The values that this snippet prints are 3 and 2 (for the major and minor dimensions respectively):

Listing: **sizeof operator and multidimensional arrays**

```
new matrix[3][2] = { { 1, 2 }, { 3, 4 }, { 5, 6 } }
printf("%d %d", sizeof matrix, sizeof matrix[]);
```

Default function arguments and sizeof: 77

The application of the sizeof operator on multi-dimensional arrays is especially convenient when used as a default value for function arguments.

• Tag names

A tag is a label that denotes the objective of —or the meaning of— a variable, a constant or a function result. Tags are optional, their only purpose is to allow a stronger compile-time error checking of operands in expressions, of function arguments and of array indices.

A tag consists of a symbol name followed by a colon; it has the same syntax as a label. A tag precedes the symbol name of a variable, constant or function. In an assignment, only the right hand of the "=" sign may be tagged.

Label syntax: 113

Examples of valid tagged variable and constant definitions are:

Listing: **tag names**

```
new bool:flag = true        /* "flag" can only hold "true" or "false" */

const error:success = 0
const error:fatal= 1
const error:nonfatal = 2

error:errno = fatal
```

The sequence of the constants `success`, `fatal` and `nonfatal` could more conveniently be declared using an `enum` instruction, as illustrated below. The enumeration instruction below creates four constants, `success`, `fatal`, `nonfatal` and `error`, all with the tag `error`.

"enum" statement: 102

Listing: **enumerations**

```
enum error {
    success,
    fatal,
    nonfatal,
}
```

A typical use of "tagged" `enum`'s is in combination with arrays. If every field of an array has a distinct purpose, you can use a tagged `enum` to declare the size of an array and to add tag checking to the array usage in a single step:

Listing: **enumerations and arrays**

```
enum rectangle
    {
    left,
    top,
    right,
    bottom
    }

new my_rect[rectangle]         /* array is declared as having 4 cells */
```

```
my_rect[left] = 10
my_rect[top] = 5
my_rect[right] = 30
my_rect[bottom] = 12

for (new i = 0; rectangle:i < rectangle; ++i)
    my_rect[rectangle:i] *= 2
```

After the declaration of "`my_rect`" above, you can access the second field of `my_rect` with "`my_rect[top]`", but saying "`my_rect[1]`" will give a parser diagnostic (a warning or error message). A tag override (or a tag *cast*) adjusts a function, constant or variable to the desired tag name. The `for` loop at the last two lines in the preceding example depicts this: the loop variable `i` is a plain, untagged cell, an it must be cast to the tag `rectangle` before using it as an index in the array `my_rect`. Note that the `enum` construct has created both a constant and a tag with the name "`rectangle`".

Tag names introduced so far started with a lower case letter; these are "weak" tags. Tag names that start with an upper case letter are "strong" tags. The difference between weak and strong tags is that weak tags may, in a few circumstances, be dropped implicitly by the PAWN parser —so that a weakly tagged expression becomes an untagged expression. The tag checking mechanism verifies the following situations:

- ◇ When the expressions on both sides of a binary operator have a different tag, or when one of the expressions is tagged and the other is not, the compiler issues a "*tag mismatch*" diagnostic. There is no difference between weak and strong tags in this situation.
- ◇ There is a special case for the assignment operator: the compiler issues a diagnostic if the variable on the left side of an assignment operator has a tag, and the expression on the right side either has a different tag or is untagged. However, if the variable on the left of the assignment operator is untagged, it accepts an expression (on the right side) with a *weak* tag. In other words, a weak tag is dropped in an assignment when the *lvalue* is untagged.
- ◇ Passing arguments to functions follows the rule for assignments. The compiler issues a diagnostic when the *formal* parameter (in a function definition) has a tag and the *actual* parameter (in the function call) either is untagged or has a different tag. However, if the formal parameter is untagged, it also accepts a parameter with any *weak* tag.

"lvalue": the variable on the left side in an assignment, see page 105

◇ An array may specify a tag for every dimension, see the "`my_rect`" example above. Tag checking array indices follows the rule of binary operator tag checking: there is no difference between weak and strong tags.

Functions

A function declaration specifies the name of the function and, between parentheses, its formal parameters. A function may also return a value. A function declaration must appear on a global level (i.e. outside any other functions) and is globally accessible.

If a semicolon follows the function declaration (rather than a statement), the declaration denotes a forward declaration of the function.

The preferred way to declare forward functions is at page 82

The `return` statement sets the function result. For example, function `sum` (see below) has as its result the value of both its arguments added together. The `return` expression is optional for a function, but one cannot use the value of a function that does not return a value.

Listing: **sum function**

```
sum(a, b)
    return a + b
```

Arguments of a function are (implicitly declared) local variables for that function. The *function call* determines the values of the arguments.

Another example of a complete definition of the function `leapyear` (which returns `true` for a leap year and `false` for a non-leap year):

Listing: **leapyear function**

```
leapyear(y)
    return y % 4 == 0 && y % 100 != 0 || y % 400 == 0
```

The logical and arithmetic operators used in the `leapyear` example are covered on pages 109 and 105 respectively.

Usually a function contains local variable declarations and consists of a compound statement. In the following example, note the `assert` statement to guard against negative values for the exponent.

"assert" statement: 113

Listing: **power function (raise to a power)**

```
power(x, y)
    {
    /* returns x raised to the power of y */
    assert y >= 0
    new r = 1
    for (new i = 0; i < y; i++)
        r *= x
    return r
    }
```

A function may contain multiple `return` statements —one usually does this to quickly exit a function on a parameter error or when it turns out that the function has nothing to do. If a function returns an array, all `return` statements must specify an array with the same size and the same dimensions.

• Function arguments (call-by-value versus call-by-reference)

The "`faculty`" function in the next program has one parameter which it uses in a loop to calculate the faculty of that number. What deserves attention is that the function modifies its argument.

Another example is function JulianToDate at page 11

Listing: **faculty.p**

```
/* Calculation of the faculty of a value */

main()
    {
    print "Enter a value: "
    new v = getvalue()
    new f = faculty(v)
    printf "The faculty of %d is %d\n", v, f
    }

faculty(n)
    {
    assert n >= 0

    new result = 1
    while (n > 0)
        result *= n--

    return result
    }
```

Whatever (positive) value that "`n`" had at the entry of the `while` loop in function `faculty`, "`n`" will be zero at the end of the loop. In the case of the `faculty` function, the parameter is passed "by value", so the change of "`n`" is local to the `faculty` function. In other words, function `main` passes "`v`" as input to function `faculty`, but upon return of `faculty`, "`v`" still has the same value as before the function call.

Arguments that occupy a single cell can be passed by value or by reference. The default is "pass by value". To create a function argument that is passed by reference, prefix the argument name with the character `&`.

Example:

Listing: **swap function**

```
swap(&a, &b)
    {
    new temp = b
    b = a
    a = temp
    }
```

To pass an array to a function, append a pair of brackets to the argument name. You may optionally indicate the size of the array; doing so improves error checking of the parser.

Example:

Listing: **addvector function**

```
addvector(a[], const b[], size)
    {
    for (new i = 0; i < size; i++)
        a[i] += b[i]
    }
```

Constant variables: 63

Arrays are always passed by reference. As a side note, array `b` in the above example does not change in the body of the function. The function argument has been declared as `const` to make this explicit. In addition to improving error checking, it also allows the PAWN parser to generate more efficient code.

To pass an array of literals to a function, use the same syntax as for array initiallers: a literal string or the series of array indices enclosed in braces (see page 100; the ellipsis for progressive initiallers cannot be used). Literal arrays can only have a single dimension.

The following snippet calls `addvector` to add five to every element of the array "`vect`":

Listing: **addvector usage**

```
new vect[3] = { 1, 2, 3 }

addvector(vect, {5, 5, 5}, 3)

/* vect[] now holds the values 6, 7 and 8 */
```

"Hello world" program: 3

The invocation of function `printf` with the string `"Hello world\n"` in the first ubiquitous program is another example of passing a literal array to a function.

• Calling functions

When inserting a function name with its parameters in a statement or expression, the function will get executed in that statement/expression. The statement that refers to the function is the "caller" and the function itself, at that point, is the "callee": the one being called.

The standard syntax for calling a function is to write the function's name, followed by a list with all explicitly passed parameters between parentheses. If no parameters are passed, or if the function does not have any, the pair of parentheses behind the function name are still present. For example, to try out the `power` function, the following program calls it thus:

Function power: 70

Listing: **example program for the power function**

```
main()
    {
    print "Please give the base value and the power to raise it to:"
    new base = getvalue()
    new power = getvalue()

    new result = power(base, power)
    printf "%d raised to the power %d is %d", base, power, result
    }
```

A function may optionally return a value. The `sum`, `leapyear` and `power` functions all return a value, but the `swap` function does not. Even if a function returns a value, the caller may ignore it.

Functions sum & leapyear: 70
Function swap: 71

For the situation that the caller ignores the function's return value, there is an alternative syntax to call the function, which is also illustrated by the preceding example program calls the `power` function. The parentheses around all function arguments are optional if the caller does not use the return value. In the last statement, the example program reads

```
printf "%d raised to the power %d is %d", base, power, result
```

rather than

```
printf("%d raised to the power %d is %d", base, power, result)
```

which does the same thing.

The syntax without parentheses around the parameter list is called the "procedure call" syntax. You can use it only if:

◇ the caller does not assign the function's result to a variable and does not use it in an expression, or as the "test expression" of an `if` statement for example;

◇ the first parameter does not start with an opening parenthesis;

◇ the first parameter is on the same line as the function name, unless you use named parameters (see the next section).

As you may observe, the procedure call syntax applies to cases where a function call behaves rather as a statement, like in the calls to `print` and `printf` in the preceding example. The syntax is aimed at making such statements appear less cryptic and friendlier to read, but not that the use of the syntax is optional.

As a side note, all parentheses in the example program presented in this section are required: the return values of the calls to `getvalue` are stored in two variables, and therefore an empty pair of parentheses must follow the function name. Function `getvalue` has optional parameters, but none are passed in this example program.

• Named parameters versus positional parameters

In the previous examples, the order of parameters of a function call was important, because each parameter is copied to the function argument with the same sequential position. For example, with the function `weekday` (which uses Zeller's congruence algorithm) defined as below, you would call `weekday(12,31,1999)` to get the week day of the last day of the preceding century.

Listing: **weekday function**

```
weekday(month, day, year)
    {
    /* returns the day of the week: 0=Saturday, 1=Sunday, etc. */
    if (month <= 2)
        month += 12, --year
    new j = year % 100
    new e = year / 100
    return (day + (month+1)*26/10 + j + j/4 + e/4 - 2*e) % 7
    }
```

Date formats vary according to culture and nation. While the format *month/day/year* is common in the United States of America, European countries often use the *day/month/year* format, and technical publications sometimes standardize on the *year/month/day* format (ISO/IEC 8824). In other words, no order of arguments in the `weekday` function is "logical" or "conventional". That being the case, the alternative way to pass parameters to a function is to use "named parameters", as in the next examples (the three function calls are equivalent):

Listing: **weekday usage —positional parameters**

```
new wkday1 = weekday( .month = 12, .day = 31, .year = 1999)

new wkday2 = weekday( .day = 31, .month = 12, .year = 1999)

new wkday3 = weekday( .year = 1999, .month = 12, .day = 31)
```

With named parameters, a period (".") precedes the name of the function argument. The function argument can be set to any expression that is valid for the argument. The equal sign ("=") does in the case of a named parameter not indicate an assignment; rather it links the expression that follows the equal sign to one of the function arguments.

One may mix positional parameters and named parameters in a function call with the restriction that all positional parameters must precede any named parameters.

• Default values of function arguments

A function argument may have a default value. The default value for a function argument must be a constant. To specify a default value, append the equal sign ("=") and the value to the argument name.

Public functions do not support default argument values; see page 83

When the function call specifies an argument placeholder instead of a valid argument, the default value applies. The argument placeholder is the underscore character ("_"). The argument placeholder is only valid for function arguments that have a default value.

The rightmost argument placeholders may simply be stripped from the function argument list. For example, if function `increment` is defined as:

Listing: **increment function —default values**

```
increment(&value, incr=1) value += incr
```

the following function calls are all equivalent:

Listing: **increment usage**

```
increment(a)
increment(a, _)
increment(a, 1)
```

Default argument values for passed-by-reference arguments are useful to make the input argument optional. For example, if the function `divmod` is designed to return both the quotient and the remainder of a division operation through its arguments, default values make these arguments optional:

Listing: **divmod function —default values for reference parameters**

```
divmod(a, b, &quotient=0, &remainder=0)
    {
    quotient = a / b
    remainder = a % b
    }
```

With the preceding definition of function `divmod`, the following function calls are now all valid:

Listing: **divmod usage**

```
new p, q

divmod(10, 3, p, q)
divmod(10, 3, p, _)
divmod(10, 3, _, q)
divmod(10, 3, p)
divmod 10, 3, p, q
```

Default arguments for array arguments are often convenient to set a default string or prompt to a function that receives a string argument. For example:

Listing: **print_error function**

```
print_error(const message[], const title[] = "Error: ")
    {
    print title
    print message
    print "\n"
    }
```

The next example adds the fields of one array to another array, and by default increments the first three elements of the destination array by one:

Listing: **addvector function, revised**

```
addvector(a[], const b[] = {1, 1, 1}, size = 3)
    {
    for (new i = 0; i < size; i++)
        a[i] += b[i]
    }
```

• sizeof operator & default function arguments

A default value of a function argument must be a constant, and its value is determined at the point of the function's *declaration*. Using the "`sizeof`" operator to set the default value of a function argument is a special case: the calculation of the value of the `sizeof` expression is delayed to the point of the function *call* and it takes the size of the *actual* argument rather than that of the *formal* argument. When the function is used several times in a program, with different arguments, the outcome of the "`sizeof`" expression is potentially different at every call —which means that the "default value" of the function argument may change.

"sizeof" operator 110

Below is an example program that draws ten random numbers in the range of 0–51 without duplicates. An example for an application for drawing random numbers without duplicates is in card games —those ten numbers could represent the cards for two "hands" in a poker game. The virtues of the algorithm used in this program, invented by Robert W. Floyd, are that it is efficient and unbiased —provided that the pseudo-random number generator is unbiased as well.

Listing: **randlist.p**

```
main()
    {
    new HandOfCards[10]
    FillRandom(HandOfCards, 52)

    print "A draw of 10 numbers from a range of 0 to 51 \
           (inclusive) without duplicates:\n"
    for (new i = 0; i < sizeof HandOfCards; i++)
        printf "%d ", HandOfCards[i]
    }

FillRandom(Series[], Range, Number = sizeof Series)
    {
    assert Range >= Number      /* cannot select 50 values
                                 * without duplicates in the
                                 * range 0..40, for example */
    new Index = 0
    for (new Seq = Range - Number; Seq < Range; Seq++)
        {
        new Val = random(Seq + 1)
        new Pos = InSeries(Series, Val, Index)
        if (Pos >= 0)
            {
            Series[Index] = Series[Pos]
            Series[Pos] = Seq
            }
        else
```

"random" is a proposed core function, see page 125

```
            Series[Index] = Val
        Index++
        }
    }

InSeries(Series[], Value, Top = sizeof Series)
    {
    for (new i = 0; i < Top; i++)
        if (Series[i] == Value)
            return i
    return -1
    }
```

Array declarations: 63

Function `main` declares the array `HandOfCards` with a size of ten cells and then calls function `FillRandom` with the purpose that it draws ten positive random numbers below 52. Observe, however, that the only two parameters that `main` passes into the call to `FillRandom` are the array `HandOfCards`, where the random numbers should be stored, and the upper bound "52". The number of random numbers to draw ("10") is passed *implicitly* to `FillRandom`.

The definition of function `FillRandom` below main specifies for its third parameter "`Number = sizeof Series`", where "`Series`" refers to the first parameter of the function. Due to the special case of a "`sizeof` default value", the default value of the `Number` argument is not the size of the formal argument `Series`, but that of the actual argument at the point of the function call: `HandOfCards`.

Note that inside function `FillRandom`, asking the "`sizeof`" the function argument `Series` would (still) evaluate in zero, because the `Series` array is declared with unspecified length (see page 110 for the behaviour of `sizeof`). Using `sizeof` as a default value for a function argument is a specific case. If the formal parameter `Series` were declared with an explicit size, as in `Series[10]`, it would be redundant to add a `Number` argument with the array size of the actual argument, because the parser would then enforce that both formal and actual arguments have the size and dimensions.

• Arguments with tag names

Tag names: 67

A tag optionally precedes a function argument. Using tags improves the compile-time error checking of the script and it serves as "implicit documentation" of the function. For example, a function that computes the square root of an input value in fixed point precision may require that the input parameter is a fixed point value and that the result is fixed point as well.

The function below uses the fixed point extension module, and an approximation algorithm known as "bisection" to calculate the square root. Note the use of tag overrides on numeric literals and expression results.

Fixed point arithmetic: 91;
see also the application note "Fixed Point Support Library"

Listing: **sqroot function —strong tags**

```
Fixed: sqroot(Fixed: value)
    {
    new Fixed: low = 0.0
    new Fixed: high = value

    while (high - low > Fixed: 1)
        {
        new Fixed: mid = (low + high) >> 1
        if (fmul(mid, mid) < value)
            low = mid
        else
            high = mid
        }

    return low
    }
```

With the above definition, the PAWN parser issues a diagnostic if one calls the `sqroot` function with a parameter with a tag different from "`Fixed:`", or when it tries to store the function result in a variable with a "*non*-`Fixed:`" tag.

The bisection algorithm is related to binary search, in the sense that it continuously halves the interval in which the result must lie. A "successive substitution" algorithm like Newton-Raphson, that takes the slope of the function's curve into account, achieves precise results more quickly, but at the cost that a stopping criterion is more difficult to state. State of the art algorithms for computing square roots combine bisection and Newton-Raphson algorithms.

In the case of an array, the array indices can be tagged as well. For example, a function that creates the intersection of two rectangles may be written as:

Listing: **intersection function**

For the "rectangle" tag, see page 67

```
intersection(dest[rectangle],
             const src1[rectangle], const src2[rectangle])
    {
```

```
    if (src1[right] > src2[left] && src1[left] < src2[right]
        && src1[bottom] > src2[top] && src1[top] < src2[bottom])
        {
        /* there is an intersection, calculate it using the "min" and
         * "max" functions from the "core" library, see page 125.
         */
        dest[left] = max(src1[left], src2[left])
        dest[right] = min(src1[right], src2[right])
        dest[top] = max(src1[top], src2[top])
        dest[bottom] = min(src1[bottom], src2[bottom])
        return true
        }
    else
        {
        /* "src1" and "src2" do not intersect */
        dest = { 0, 0, 0, 0 }
        return false
        }

    }
```

• Variable arguments

A function that takes a variable number of arguments, uses the "ellipsis" operator ("...") in the function header to denote the position of the first variable argument. The function can access the arguments with the predefined functions `numargs`, `getarg` and `setarg` (see page 125).

Function `sum` returns the summation of all of its parameters. It uses a variable length parameter list.

Listing: **sum function, revised**

```
sum(...)
    {
    new result = 0
    for (new i = 0; i < numargs(); ++i)
        result += getarg(i)
    return result
    }
```

This function could be used in:

Listing: **sum function usage**

```
new v = sum(1, 2, 3, 4, 5)
```

A tag may precede the ellipsis to enforce that all subsequent parameters have the same tag, but otherwise there is no error checking with a variable argument list and this feature should therefore be used with caution.

Tag names: 67

The functions `getarg` and `setarg` assume that the argument is passed "by reference". When using `getarg` on normal function parameters (instead of variable arguments) one should be cautious of this, as neither the compiler nor the abstract machine can check this. Actual parameters that are passed as part of a "variable argument list" are always passed by reference.

• Coercion rules

If the function argument, as per the function definition (or its declaration), is a "value parameter", the caller can pass as a parameter to the function:
◇ a value, which is passed by value;
◇ a reference, whose dereferenced value is passed;
◇ an (indexed) array element, which is a value.

If the function argument is a reference, the caller can pass to the function:
◇ a value, whose address is passed;
◇ a reference, which is passed by value because it has the type that the function expects;
◇ an (indexed) array element, which is a value.

If the function argument is an array, the caller can pass to the function:
◇ an array with the same dimensions, whose starting address is passed;
◇ an (indexed) array element, in which case the address of the element is passed.

• Recursion

A `faculty` example function earlier in this chapter used a simple loop. An example function that calculated a number from the Fibonacci series also used a loop and an extra variable to do the trick. These two functions are the most popular routines to illustrate recursive functions, so by implementing these as iterative procedures, you might be inclined to think that PAWN does not support recursion.

"faculty": 71
"fibonacci": 9

Well, PAWN *does* support recursion, but the calculation of faculties and of Fibonacci numbers happen to be good examples of when *not* to use recursion. Faculty is easier to understand with a loop than it is with recursion. Solving

Fibonacci numbers by recursion indeed simplifies the problem, but at the cost of being extremely inefficient: the recursive Fibonacci calculates the same values over and over again.

There exists an intriguing iterative solution to the Towers of Hanoi.

The program below is an implementation of the famous "Towers of Hanoi" game in a recursive function:

Listing: **hanoi.p**

```
/* The Towers of Hanoi, a game solved through recursion */

main()
    {
    print "How many disks: "
    new disks = getvalue()
    move 1, 3, 2, disks
    }

move(from, to, spare, numdisks)
    {
    if (numdisks > 1)
        move from, spare, to, numdisks-1
    printf "Move disk from pillar %d to pillar %d\n", from, to
    if (numdisks > 1)
        move spare, to, from, numdisks-1
    }
```

• Forward declarations

For standard functions, the current "reference implementation" of the PAWN compiler does not require functions to be declared before their first use.* User-defined operators are special functions, and unlike standard functions they *must* be declared before use. In many cases it is convenient to put the implementation of a user-defined operator in an include file, so that the implementation and declaration precedes any call/invocation. Sometimes, it may however be required (or convenient) to declare a user- defined operator first and implement it elsewhere. A particular use of this technique is to implement "forbidden" user-defined operators.

Forbidden user-defined operators: 92

To create a forward declaration, precede the function name and its parameter list with the keyword `forward`. For compatibility with early versions of PAWN, and for similarity with C/C++, an alternative way to forwardly

* Other implementations of the Pawn language (if they exist) may use "single pass" parsers, requiring functions to be defined before use.

declare a function is by typing the function header and terminating it with a semicolon (which follows the closing parenthesis of the parameter list).

The full definition of the function, with a non-empty body, is implemented elsewhere in the source file (except for forbidden user-defined operators).

State classifiers are ignored on forward declarations.

• State classifiers

Example: 39

All functions except native functions may optionally have a state attribute. This consists of a list of state (and automata) names between angle brackets behind the function header. The names are separated by commas. When the state is part of a non-default automaton, the name of the automaton and a colon separator must precede the state; for example, "`parser:slash`" stands for the state `slash` of the automaton `parser`.

If a function has states, there must be several "implementations" of the function in the source code. All functions must have the same function header (excluding the state classifier list).

As a special syntax, when there are *no* names between the angle brackets, the function is linked to all states that are not attributed to other implementations of the function. The function that handles "all states not handled elsewhere" is the so-called *fall-back* function.

• Public functions, function main

A stand-alone program must have the function `main`. This function is the starting point of the program. The function `main` may not have arguments.

A function library need not to have a `main` function, but it must have it either a `main` function, *or* at least one public function. Function `main` is the primary entry point into the compiled program; the public functions are alternative entry points to the program. The virtual machine can start execution with one of the public functions. A function library may have a `main` function to perform one-time initialization at start-up.

To make a function public, prefix the function name with the keyword `public`. For example, a text editor may call the public function "`onkey`" for every key that the user typed in, so that the user can change (or reject) keystrokes. The `onkey` function below would replace every "`~`" character

(code 126 in the ISO Latin-1 character set) by the "hard space" code in the ANSI character table:

Listing: **onkey function**

```
public onkey(keycode)
    {
    if (key=='~')
        return 160      // replace ~ by hard space (code 160 in Latin-1)
    else
        return key      // leave other keys unaltered
    }
```

Functions whose name starts with the "@" symbol are also public. So an alternative way to write the public function `onkey` function is:

Listing: **@onkey function**

```
@onkey(keycode)
    return key=='~' ? 160 : key
```

The "@" character, when used, becomes part of the function name; that is, in the last example, the function is called "`@onkey`". The host application decides on the names of the public functions that a script may implement.

Default values of function arguments: 75

Arguments of a public function may not have default values. A public function interfaces the host application to the PAWN script. Hence, the arguments passed to the public function originate from the host application, and the host application cannot know what "default values" the script writer plugged for function arguments —which is why the PAWN parser flags the use of default values for arguments of public functions as an error. The issue of default values in public function arguments only pops up in the case that you wish to call public functions from the script itself.

• Static functions

When the function name is prefixed with the keyword `static`, the scope of the function is restricted to the file that the function resides in.

The `static` attribute can be combined with the "`stock`" attribute.

• Stock functions

A "stock" function is a function that the PAWN parser must "plug into" the program when it is used, and that it may simply "remove" from the program (without warning) when it is not used. Stock functions allow a

compiler or interpreter to optimize the memory footprint and the file size of a (compiled) PAWN program: any stock function that is not referred to, is completely skipped —as if it were lacking from the source file.

A typical use of stock functions, hence, is in the creation of a set of "library" functions. A collection of general purpose functions, all marked as "stock" may be put in a separate include file, which is then included in any PAWN script. Only the library functions that are actually used get "linked" in.

To declare a stock function, prefix the function name with the keyword `stock`. Public functions and native functions cannot be declared "stock".

Public variables can be declared "stock"

When a stock function calls other functions, it is usually a good practice to declare those other functions as "stock" too —with the exception of native functions. Similarly, any global variables that are used by a stock function should in most cases also be defined "stock". The removal of unused (stock) functions can cause a chain reaction in which other functions and global variables are not longer accessed either. Those functions are then removed as well, thereby continuing the chain reaction until only the functions that are used, directly or indirectly, remain.

Stock variables: 62

• Native functions

A PAWN program can call application-specific functions through a "native function". The native function must be declared in the PAWN program by means of a function prototype. The function name must be preceded by the keyword `native`.

Examples:

```
native getparam(a[], b[], size)

native multiply_matrix(a[], b[], size)

native openfile(const name[])
```

The names "`getparam`", "`multiply_matrix`" and "`openfile`" are the *internal* names of the native functions; these are the names by which the functions are known in the PAWN program. Optionally, you may also set an *external* name for the native function, which is the name of the function as the "host application" knows it. To do so, affix an equal sign to the function prototype followed by the external name. For example:

```
native getparam(a[], b[], size) = host_getparam
```

```
native multiply_matrix(a[], b[], size) = mtx_mul
```

When a native function returns an array, the dimensions and size of the array must be explicitly declared. The array specification occurs between the function name and the parameter list. For example:

```
enum rect { left, top, right, bottom }
native intersect[rect](src1[rect], src2[rect])
```

An example of a native user-defined operator is on page 90

Unless specified explicitly, the external name is equal to the internal name of a native function. One typical use for explicit external names is to set a symbolic name for a user-defined operator that is implemented as a native function.

See the "Implementer's Guide" for implementing native functions in C/C^{++} (on the "host application" side).

Native functions may not have state specifiers.

• User-defined operators

Tags: 67

The only data type of PAWN is a "cell", typically a 32-bit number or bit pattern. The meaning of a value in a cell depends on the particular application —it need not always be a signed integer value. PAWN allows to attach a "meaning" to a cell with its "tag" mechanism.

Based on tags, PAWN also allows you to redefine operators for cells with a specific purpose. The example below defines a tag "`ones`" and an operator to add two "ones" values together (the example also implements operators for subtraction and negation). The example was inspired by the checksum algorithm of several protocols in the TCP/IP protocol suite: it simulates one's complement arithmetic by adding the carry bit of an arithmetic overflow back to the least significant bit of the value.

Listing: **ones.p**

```
forward ones: operator+(ones: a, ones: b)
forward ones: operator-(ones: a, ones: b)
forward ones: operator-(ones: a)

main()
    {
    new ones: chksum = ones: 0xffffffff
    print "Input values in hexadecimal, zero to exit\n"
```

```
    new ones: value
    do
        {
        print ">> "
        value = ones: getvalue(.base=16)
        chksum = chksum + value
        printf "Checksum = %x\n", chksum
        }
    while (value)
    }

stock ones: operator+(ones: a, ones: b)
    {
    const ones: mask =  ones: 0xffff    /* word mask */
    const ones: shift = ones: 16        /* word shift */

    /* add low words and high words separately */
    new ones: r1 = (a & mask) + (b & mask)
    new ones: r2 = (a >>> shift) + (b >>> shift)

    new ones: carry
    restart:            /* code label (goto target) */

    /* add carry of the new low word to the high word, then
     * strip it from the low word
     */
    carry = (r1 >>> shift)
    r2 += carry
    r1 &= mask

    /* add the carry from the new high word back to the low
     * word, then strip it from the high word
     */
    carry = (r2 >>> shift)
    r1 += carry
    r2 &= mask

    /* a carry from the high word injected back into the low
     * word may cause the new low to overflow, so restart in
     * that case
     */
    if (carry)
        goto restart

    return (r2 << shift) | r1
    }

stock ones: operator-(ones: a)
    return (a == ones: 0xffffffff) ? a : ~a

stock ones: operator-(ones: a, ones: b)
    return a + -b
```

The notable line in the example is the line "`chksum = chksum + value`" in the loop in function `main`. Since both the variables `chksum` and `value` have the tag `ones`, the "`+`" operator refers to the user-defined operator (instead of the default "`+`" operator). User-defined operators are merely a notational convenience. The same effect is achieved by calling functions explicitly.

The definition of an operator is similar to the definition of a function, with the difference that the name of the operator is composed by the keyword "`operator`" and the character of the operator itself. In the above example, both the unary "`-`" and the binary "`-`" operators are redefined. An operator function for a binary operator must have two arguments, one for an unary operator must have one argument. Note that the binary "`-`" operator adds the two values together after inverting the sign of the second operand. The subtraction operator thereby refers to both the user-defined "negation" (unary "`-`") and addition operators.

A redefined operator must adhere to the following restrictions:

Forward declaration: 82

- ◇ A user-defined operator must be declared before use (this is in contrast to "normal" functions): either put the implementation of the user-defined operator above the functions that use it, or add a forward declaration near the top of the file.
- ◇ Only the following operators may be redefined: `+`, `-`, `*`, `/`, `%`, `++`, `--`, `==`, `!=`, `<`, `>`, `<=`, `>=`, `!` and `=`. That is, the sets of arithmetic and relational operators can be overloaded, but the bitwise operators and the logical operators cannot. The `=` and `!` operators are a special case.
- ◇ You cannot invent new operators; you cannot define operator "`#`" for example.
- ◇ The precedence level and associativity of the operators, as well as their "arity" remain as defined. You cannot make an unary "`+`" operator, for example.
- ◇ The return tag of the relational operators and of the "`!`" operator must be "`bool:`".
- ◇ The return tag of the arithmetic operators is at your choosing, but you cannot redefine an operator that is identical to another operator except for its return tag. For example, you cannot make both

```
alpha:  operator+(alpha:  a, alpha:  b)
```

  and

```
beta:  operator+(alpha:  a, alpha:  b)
```

  (The assignment operator is an exception to this rule.)

- ◇ PAWN already defines operators to work on untagged cells, you cannot redefine the operators with only arguments without tags.
- ◇ The arguments of the operator function must be non-arrays passed by value. You cannot make an operator work on arrays.

In the example given above, both arguments of the binary operators have the same tag. This is not required; you may, for example, define a binary "`+`" operator that adds an integer value to a "`ones:`" number.

Au fond, the operation of the PAWN parser is to look up the tag(s) of the operand(s) that the operator works on and to look up whether a user-defined operator exists for the combination of the operator and the tag(s). However, the parser recognizes special situations and provides the following features:

- ◇ The parser recognizes operators like "`+=`" as a sequence of "`+`" and "`=`" and it will call a user-defined operator "`+`" if available and/or a user-defined operator "`=`". In the example program, the line "`chksum = chksum + value`" might have been abbreviated to "`chksum += value`".
- ◇ The parser recognizes commutative operators ("`+`", "`*`", "`==`", and "`!=`") and it will swap the operands of a commutative operator if that produces a fit with a user-defined operator. For example, there is usually no need to implement both

  ```
  ones:operator+(ones:a, b)
  ```

  and

  ```
  ones:operator+(a, ones:b)
  ```

  (implementing both functions is valid, and it is useful in case the user-defined operator should not be commutative).
- ◇ Prefix and postfix operators are handled automatically. You only need to define one user operator for the "`++`" and "`--`" operators for a tag.
- ◇ The parser calls the "`!`" operator implicitly in case of a test without explicit comparison. For example, in the statement "`if (var) ...`" when "`var`" has tag "`ones:`", the user-defined operator "`!`" will be called for `var`. The "`!`" operator thus doubles as a "test for zero" operator. (In one's complement arithmetic, both the "all-ones" and the "all-zeros" bit patterns represent zero.)
- ◇ The user-defined assignment operator is implicitly called for a function argument that is passed "by value" when the tag names of the *formal* and the *actual* arguments match the tag names of the left and right hand sides of the operator. In other words, the PAWN parser simulates that "pass by value" happens through assignment. The user-defined operator is not called for function arguments that are passed "by reference".

"Call by value" versus "call by reference": 71

◇ If you wish to forbid an operation, you can "forward declare" the operator without ever defining it (see page 82). This will flag an error when the user-defined operator is invoked. For example, to forbid the "`%`" operator (remainder after division) on floating point values, you can add the line:

```
forward Float:  operator%(Float:  a, Float:  b)
```

Native functions: 85

User-defined operators can optionally be declared "`stock`" or "`native`". In the case of a native operator function, the definition should include an external name. For example (when, on the host's side, the native function is called `float_add`):

Listing: **native operator+ function**

```
native Float: operator+(Float: val, Float: val) = float_add
```

The user-defined assignment operator is a special case, because it is an operator that has a side effect. Although the operator has the appearance of a binary operator, its "expression result" is the value at the right hand —the assignment operator would be a "null"-operator if it weren't for its side-effect. In PAWN a user-defined assignment operator is declared as:

Listing: **operator= function**

```
ones: operator=(a)
    return ones: ( (a >= 0) ? a : ~(-a) )
```

The user-defined "`=`" operator looks like a unary operator in this definition, but it is a special case nevertheless. In contrast to the other operators, the tag of the return value for the user-defined operator is important: the PAWN parser uses the tags of the argument and the return value to find a matching user-defined operator.

The example function above is a typical application for a user-defined assignment operator: to automatically coerce/convert an untagged value to a tagged value, and to optionally change the memory representation of the value in the process. Specifically, the statement "`new ones:A = -5`" causes the user-defined operator to run, and for the constant `-5` the operator will return "`~(- -5)`", or `~5`, or −6.*

* Modern CPUs use two's complement integer arithmetic. For positive values, the bitwise representation of a value is the same in one's complement and two's complement, but the representations differ for negative values. For instance, the same bit pattern that means -5 in one's complement stands for -6 in two's complement.

• Floating point and fixed point arithmetic

PAWN only has intrinsic support for integer arithmetic (the $\mathbb{Z}$-domain, or "whole numbers", both positive and negative). Support for floating point arithmetic or fixed point arithmetic must be implemented through (native) functions. User operators, then, allow a more natural notation of expressions with fixed or floating point numbers.

The PAWN parser has support for literal values with a fractional part, which it calls "rational numbers". Support for rational literals must be enabled explicitly with a `#pragma`. The `#pragma` indicates how the rational numbers must be stored —floating point or fixed point. For fixed point rational values, the `#pragma` also specifies the precision in decimals. Two examples for the `#pragma` are:

Rational literals: 99
#pragma rational: 123

```
#pragma rational Float      /* floating point format */
#pragma rational Fixed(3)   /* fixed point, with 3 decimals */
```

Since a fixed point value must still fit in a cell, the number of decimals has a direct influence of the range of a fixed point value. For a fixed point value with 3 decimals, the range would be $-2,147,482 \ldots + 2,147,482$.

The format for a rational number may only be specified once for the entire PAWN program. In an implementation one typically chooses either floating point support or fixed point support. As stated above, for the actual implementation of the floating point or fixed point arithmetic, PAWN requires the help of (native) functions and user-defined operators. A good place to put the `#pragma` for rational number support would be in the include file that also defines the functions and operators.

The include file † for fixed point arithmetic contains definitions like:

```
native Fixed: operator*(Fixed: val1, Fixed: val2) = fmul
native Fixed: operator/(Fixed: val1, Fixed: val2) = fdiv
```

The user-defined operators for multiplication and division of two fixed point numbers are aliased directly to the native functions `fmul` and `fdiv`. The host application must, then, provide these native functions.

Another native user-defined operator is convenient to transform an integer to fixed point automatically, if it is assigned to a variable tagged as "`Fixed:`":

† See the application note "Fixed Point Support Library" for where to obtain the include file.

```
native Fixed: operator=(oper) = fixed
```

User-defined operators: 86

With this definition, you can say "`new Fixed: fract = 3`" and the value will be transformed to `3.000` when it is stored in variable `fract`. As explained in the section on user-defined operators, the assignment operator also runs for function arguments that are passed by value. In the expression "`new Fixed: root = sqroot(16)`" (see the implementation of function `sqroot` on page 79), the user-defined assignment operator is called on the argument `16`.

For adding two fixed point values together, the default "`+`" operator is sufficient, and the same goes for subtraction. Adding a normal (integer) number to a fixed point number is different: the normal value must be scaled before adding it. Hence, the include file implements operators for that purpose too:

Listing: **additive operators, commutative and non-commutative**

```
stock Fixed: operator+(Fixed: val1, val2)
    return val1 + fixed(val2)

stock Fixed: operator-(Fixed: val1, val2)
    return val1 - fixed(val2)

stock Fixed: operator-(val1, Fixed: val2)
    return fixed(val1) - val2
```

The "`+`" operator is commutative, so one implementation handles both cases. For the "`-`" operator, both cases must be implemented separately.

Finally, the include file forbids the use of the remainder operator ("`%`") on fixed point values: the remainder is only applicable to integer divisions:

Listing: **forbidden operators on fixed point values**

```
forward Fixed: operator%(Fixed: val1, Fixed: val2)
forward Fixed: operator%(Fixed: val1, val2)
forward Fixed: operator%(val1, Fixed: val2)
```

Because of the presence of the (forward) declaration of the operator, the PAWN parser will attempt to use the user-defined operator rather than the default "`%`" operator. By not implementing the operator, the parser will subsequently issue an error message.

The preprocessor

The first phase of compiling a PAWN source file to the executable P-code is "preprocessing": a general purpose text filter that modifies/cleans up the text before it is fed into the parser. The preprocessing phase removes comments, strips out "conditionally compiled" blocks, processes the compiler directives and performs find-&-replace operations on the text of the source file. The compiler directives are summarized on page 118 and the text substitution ("find-&-replace") is the topic of this chapter.

The preprocessor is a process that is invoked on all source lines immediately after they are read. No syntax checking is performed during the text substitutions. While the preprocessor allows powerful tricks in the PAWN language, it is also easy to shoot yourself in the foot with it.

In this chapter, I will refer to the C/C^{++} language on several occasions because PAWN's preprocessor is similar to the one in C/C^{++}. That said, the PAWN preprocessor is incompatible with the C/C^{++} preprocessor.

The `#define` directive defines the preprocessor macros. Simple macros are:

```
#define maxsprites       25
#define CopyRightString  "(c) Copyright 2004 by me"
```

In the PAWN script, you can then use them as you would use constants. For example:

```
#define maxsprites  25
#define CopyRightString "(c) Copyright 2004 by me"
main()
    {
    print( Copyright )
    new sprites[maxsprites]
    }
```

By the way, for these simple macros there are equivalent PAWN constructs:

```
const maxsprites = 25
stock const CopyRightString[] = "(c) Copyright 2004 by me"
```

These constant declarations have the advantage of better error checking and the ability to create tagged constants. The syntax for a string constant is an array variable that is declared both "`const`" and "`stock`". The `const` attribute prohibits any change to the string and the `stock` attribute makes the declaration "disappear" if it is never referred to.

Substitution macros can take up to 10 parameters. A typical use for macros with parameters is to simulate tiny functions:

Listing: **the "min" macro**

```
#define min(%1,%2)      ((%1) < (%2) ? (%1) : (%2))
```

If you know C/C++, you will recognize the habit of enclosing each argument and the whole substitution expression in parentheses.

If you use the above macro in a script in the following way:

Listing: **bad usage of the "min" macro**

```
new a = 1, b = 4
new min = min(++a,b)
```

the preprocessor translates it to:

```
new a = 1, b = 4
new min = ((++a) < (b) ? (++a) : (b))
```

which causes "a" to possibly be incremented twice. This is one of the traps that you can trip into when using substitution macros (this particular problem is well known to C/C++ programmers). Therefore, it may be a good idea to use a naming convention to distinguish macros from functions. In C/C++ it is common practice to write preprocessor macros in all upper case.

To show why enclosing macro arguments in parentheses is a good idea, consider the macro:

```
#define ceil_div(%1,%2) (%1 + %2 - 1) / %2
```

This macro divides the first argument by the second argument, but rounding *upwards* to the nearest integer (the divide operator, "/", rounds downwards). If you use it as follows:

```
new a = 5
new b = ceil_div(8, a - 2)
```

Operator precedence: 111

the second line expands to "`new b = (8 + a - 2 - 1) / a - 2`", which, considering the precedence levels of the PAWN operators, leads to "b" being set to zero (if "a" is 5). What you would have expected from looking at the macro invocation is eight divided by three ("`a - 2`"), rounded upwards — hence, that "b" would be set to the value 3. Changing the macro to enclose each parameter in parentheses solves the problem. For similar reasons, it is also advised to enclose the complete replacement text in parentheses. Below is the `ceil_div` macro modified accordingly:

```
#define ceil_div(%1,%2) ( ((%1) + (%2) - 1) / (%2) )
```

The pattern matching is subtler than matching strings that look like function calls. The pattern matches text literally, but accepts arbitrary text where the pattern specifies a parameter. You can create patterns like:

Listing: **macro that translates a syntax for array access to a function call**

```
#define Object[%1]      CallObject(%1)
```

When the expansion of a macro contains text that matches other macros, the expansion is performed at invocation time, not at definition time. Thus the code:

```
#define a(%1)      (1+b(%1))
#define b(%1)      (2*(%1))
new c = a(8)
```

will evaluate to "`new c = (1+(2*(8)))`", even though the macro "`b`" was not defined at the time of the definition of "`a`".

If an argument in the replacement text has a "`#`" immediately in front of it, the argument is converted to a string constant —meaning that double quotes are tagged at the beginning and the end. For example, if you have the definition:

```
#define log(%1) "ERR: " ... #%1 ... "\n"
```

then the expression `log(test)` will result in `"ERR: " ... "test" ... "\n"`. The "`#`" operator is also called the "stringize" operator, as it converts arguments to strings.

See page 101 for concatenating literal strings with the "..." operator

The pattern matching is constrained to the following rules:

- There may be *no space characters* in the pattern. If you must match a space, you need to use the "`\32;`" escape sequence. The substitution text, on the other hand, *may* contain space characters. Due to the matching rules of the macro pattern (explained below), matching a space character is rarely needed.
- As evidenced in the preceding line, escape sequences may appear in the pattern (they are not very useful, though, except perhaps for matching a literal "`%`" character).
- The pattern may not end with a parameter; a pattern like "`set:%1=%2`" is illegal. If you wish to match with the end of a statement, you can add a semicolon at the end of the pattern. If semicolons are optional at the end of each statement, the semicolon will also match a newline in the source.
- The pattern must start with a letter, an underscore, or an "`@`" character The first part of the pattern that consists of alphanumeric characters (plus the "`_`" and/"`@`") is the "name" or the "prefix" of the macro. On the `defined` operator and the `#undef` directive, you specify the macro prefix.

◇ When matching a pattern, the preprocessor ignores white space between non-alphanumeric symbols and white space between an alphanumeric symbol and a non-alphanumeric one, with one exception: between two identical symbols, white space is not ignored. Therefore:
the pattern `abc(+-)` matches "`abc ( + - )`"
the pattern `abc(--)` matches "`abc ( -- )`" but does not match "`abc(- -)`"

◇ There are up to 10 parameters, denoted with a "`%`" and a single digit (1 to 9 and 0). The order of the parameters in a pattern is not important.

Directives: 118

◇ The `#define` symbol is a parser *directive*. As with all parser directives, the pattern definition must fit on a single line. You can circumvent this with a "\" on the end of the line. The text to match must also fit on a single line.

Note that in the presence of (parametrized) macros, lines of source code may not be what they appear: what looks like an array access may be "preprocessed" to a function call, and vice versa.

A host application that embeds the PAWN parser may provide an option to let you check the result of text substitution through macros. If you are using the standard PAWN toolset, you will find instructions of how to use the compiler and run-time in the companion booklet "The PAWN booklet — Implementer's Guide".

General syntax

Format

Identifiers, numbers and tokens are separated by spaces, tabs, carriage returns and "form feeds". Series of one or more of these separators are called white space.

Optional semicolons

Semicolons (to end a statement) are optional if they occur at the end of a line. Semicolons are required to separate multiple statements on a single line. An expression may still wrap over multiple lines, but postfix operators (`++`, `--` and `char`) *must* appear on the same line as their operand.

Optional semicolons: 123

Comments

Text between the tokens `/*` and `*/` (both tokens may be at the same line or at different lines) and text behind `//` (up to the end of the line) is a programming comment. The parser treats a comment as white space. Comments may not be nested.

A comment that starts with "`/**` " (two stars and white-space behind the second star) and ends with "`*/`" is a documentation comment. A comment that starts with "`///` " (three slashes and white-space behind the third slash) is also a documentation comment. The parser may treat documentation comments in a special way; for example, it may construct on-line help from it.

Identifiers

Names of variables, functions and constants. Identifiers consist of the characters `a...z`, `A...Z`, `0...9`, `_` or `@`; the first character may not be a digit. The characters `@` and `_` by themselves are not valid identifiers, i.e. "`_Up`" is a valid identifier, but "`_`" is not.

PAWN is case sensitive.

A parser may truncate an identifier after a maximum length. The number of significant characters is implementation defined, but it is at least 16 characters.

Reserved words (keywords)

Statements	Operators	Directives	Other

assert	char	#assert	const
break	defined	#define	enum
case	sizeof	#else	forward
continue	state	#elseif	native
default	tagof	#endif	new
do		#endinput	operator
else		#error	public
exit		#file	static
for		#if	stock
goto		#include	
if		#line	
return		#pragma	
sleep		#section	
state		#tryinclude	
switch		#undef	
while			

Predefined constants: 103

Next to reserved words, PAWN also has several predefined constants, you cannot use the symbol names of the predefined constants for variable or function names.

Constants (literals)

Integer numeric constants

binary

`0b` followed by a series of the digits 0 and 1

decimal

a series of digits between 0 and 9

hexadecimal

`0x` followed by a series of digits between 0 and 9 and the letters `a` to `f`

In all number radices, the single quote may be used as a "digit group separator". For decimal numbers, the quote separates 3 digits (thousands separator), for binary numbers, the quote separates 8 digits and for hexadecimal numbers, a quote separates 4 (hexadecimal) digits. Using the single quote as a digit group separator is optional, but if used, the number of digits after the quote must conform to the above specification.

Rational number constants

Rational numbers are also called "real numbers" or "floating point numbers"

A rational number is a number with a fractional part. A rational number starts with one or more digits, contains a decimal point and has at least one digit following the decimal point. For example, "12.0" and "0.75" are valid rational numbers. Optionally, an exponent may be appended to the rational number; the exponent notation is the letter "`e`" (lower case) followed by a signed integer numeric constant. For example, "3.12e4" is a valid rational number with an exponent.

#pragma rational: 123

Support for rational numbers must be enabled with `#pragma rational` directive. Depending on the options set with this directive, the rational number represents a floating point or a fixed point number.

The single quote may be used as a "thousands separator" (separating 3 digits) in the "whole part" of the number.

Character constants

A single ASCII character surrounded by single quotes is a character constant (for example: `'a'`, `'7'`, `'$'`). Character constants are assumed to be numeric constants.

Escape sequences

`'\a'`		Audible alarm (beep)
`'\b'`		Backspace
`'\e'`		Escape
`'\f'`		Form feed
`'\n'`		New-line
`'\r'`		Carriage Return
`'\t'`		Horizontal tab
`'\v'`		Vertical tab
`'\\'`	`\`	the escape character
`'\''`	`'`	single quote
`'\"'`	`"`	double quote
`'\%'`	`%`	percent sign
`'\`*ddd*`;'`		character code with *decimal* code "*ddd*"
`'\x`*hhh*`;'`		character code with *hexadecimal* code "*hhh*"

The semicolon after the `\`*ddd*`;` and `\x`*hhh*`;` codes is optional.

Its purpose is to give the escape sequence sequence an explicit termination symbol when it is used in a string constant.

The backslash ("\") is the default "escape" character. If desired, you can set a different escape character with the `#pragma ctrlchar` directive (page 121).

String constants

String constants are assumed to be arrays with a size that is sufficient to hold all characters plus a terminating `'\0'`. Each string is stored at a unique position in memory; there is no elimination of duplicate strings.

An *unpacked* string is a series of zero or more ASCII characters surrounded by double quotes. Each array element contains a single character. An unpacked string can hold characters in a multi-byte character set, such as Unicode or UCS-4.

unpacked string constant:

```
"the quick brown fox..."
```

A *packed* string literal follows the syntax for an unpacked string, but a "`!`" precedes the first double quote.

The syntaxes for packed literal strings and unpacked literal strings can be swapped with the "#pragma pack" directive, see page 122

packed string constant:

```
!"...packed and sacked the lazy dog"
```

In the case of a packed string, the parser packs as many characters in a cell as will fit. A character is not addressable as a single unit, instead each element of the array contains multiple characters. The first character in a "pack" occupies the highest bits of the array element. In environments that store memory words with the high byte at the lower address (Big Endian, or Motorola format), the individual characters are stored in the memory cells in the same order as they are in the string. A packed string ends with a zero character and the string is padded (with zero bytes) to a multiple of cells.

A packed string can only hold characters from a *single-byte* character set, such as ASCII or one of the extended ASCII sets

from the ISO 8859 norm.

Escape sequences may be used within strings. See the section on character constants (page 99) for a list of escape sequences.

There is an alternative syntax for "plain strings". In a plain string, every character is taken as-is and escape sequences are not recognized. Plain strings are convenient to store file/resource names, especially in the case where the escape character is also used as a special character by the operating system or host application.

The syntax for a plain string is the escape character followed by the string in double quotes. The backslash ("\") is the default "escape" character. You cannot enter escape sequences in a plain string: all characters will be taken literally.

plain string constant:

```
\"C:\all my work\novel.rtf"
```

In the above example, the occurrences of "`\a`" and "`\n`" do *not* indicate escape sequences, but rather the literal character pairs "\" and "`a`", and "\" and "`n`".

A *packed* plain string has both the "!" and the escape character prefixing the opening double quote. Both strings below are packed plain strings:

```
!\"C:\all my work\novel.rtf"
\!"C:\all my work\novel.rtf"
```

Two string literals may be concatenated by inserting with an ellipsis operator (three dots, or "`...`") between the strings. For example:

```
"The quick" ...  "brown fox"
```

This syntax works with packed, unpacked and raw strings. Different kinds of string literals should not be combined in literal string concatenation, though. String concatenation is valid for string *literals* only —string variables must be concatenated with a library function or run-time code.

Array constants

A series of numeric constants between braces is an array

constant. Array constants can be used to initialize array variables with (see page 64) and they can be passed as function arguments (see page 71).

Symbolic constants

A source file declares symbolic constants with the `const` and the `enum` instructions. The `const` keyword declares a single constant and the `enum` defines a list of —usually— sequential constants sharing the same tag name.

const *identifier* = *constant expression*

Examples: 7, 19

Creates a symbolic constant with the value of the constant expression on the right hand of the assignment operator. The constant can be used at any place where a literal number is valid (for example: in expressions, in array declarations and in directives like "`#if`" and "`#assert`").

enum *name* (*increment*) { *constant list* }

Identifiers: 97

The `enum` instruction creates a series of constants with incrementing values. The *constant list* is a series of identifiers separated by commas. Unless overruled, the first constant of an `enum` list has the value 0 and every subsequent constant has the value of its predecessor plus 1.

Examples: 19, 24

Both the value of a constant and the increment value can be set by appending the value to the constant's identifier. To set a value, use

name `=` *value*

in the constant list. To set the increment, use:

name `[` *increment* `]`

The increment value is reset to 1 after every constant symbol declaration in the constant list.

If both an increment and a value should be set for a constant, the increment ("`[...]`" notation) should precede the value ("`=`" notation.

The symbols in the constant list may have an explicit tag, which should precede the symbol name.

The *name* token that follows the `enum` keyword is optional. If it is included, and if the symbol names does not have an explicit tag, this name is used as the tag name for every

symbol in the constant list. In addition, the `enum` command creates an extra constant with *name* for the constant name and the tag name. The value of the last constant is the value of the last symbol in the constant list plus the increment value of that last constant.

See page 67 for examples of the "enum" constant declarations

Enumeration fields that have a tag may override other fields in different enumerations, provided that both enumerations have a tag name. When the enumeration field is used in an expression, and notably when it is used as an array index, the constant to use is selected based on the expected tag.

The *increment* token that follows the optional *name* token is also optional. If included, it specifies a different post-increment rule. By default, an `enum` increments the value of every successive constant with 1, but you may specify a different rule with the syntax "(*operator constant*)", where *operator* must be `+=`, `*=` or `<<=`. The `+=` operator creates an additive increment, the `*=` and `<<=` create a multiplicative increment. The *constant* may be a literal value or a symbolic constant. The increment rule *must* be enclosed in parentheses. If no increment rule is specified, the parenthesis may be omitted as well.

See page 24 for an example of a custom increment rule

A symbolic constant that is defined locally, is valid throughout the block. A local symbolic constant may not have the same name as a variable (local or global), a function, or another constant (local or global).

Predefined constants

`cellbits` The size of a cell in bits; usually 32.

`cellmax` The largest valid positive value that a cell can hold; usually 2147483647.

`cellmin` The largest valid negative value that a cell can hold; usually -2147483648.

`charbits` The size of a *packed* character in bits; usually 8.

`charmax` The largest valid *packed* character value; a packed character is usually 8-bit and the maximum valid value is thus 255.

`charmin` The smallest valid character value, for both packed and unpacked values; currently set to zero (0).

`debug` The debug level: 2 if the parser creates full symbolic information plus run-time bounds checking, 1 if the parser generates run-time checking only (assertions and array bounds checks), and 0 (zero) if all debug support and run-time checking was turned off.

`false` 0 (this constant is tagged as `bool:`).

`__line` The current line number in the source file.

`__Pawn` The version number of the PAWN compiler in Binary Coded Decimals (BCD) —that is, for version 2.8.1 the constant is "`0x281`".

`true` 1 (this constant is tagged as `bool:`).

`ucharmax` The largest *unpacked* character value, its value depends on the size of a cell. A typical use for this constant is in checking whether a string is packed or unpacked, see page 137.

Tag names

Identifiers: 97

A tag consists of an identifier followed by a colon. There may be no white space between the identifier and the colon.

Predefined tag names

`bool:` For "true/false" flags. The predefined constants `true` and `false` have this tag.

`Fixed:` Rational numbers have this tag when fixed point support is enabled (page 123).

`Float:` Rational numbers have this tag when floating point support is enabled (page 123).

Operators and expressions

• Notational conventions

The operation of some operators depends on the specific kinds of operands. Therefore, operands are notated thus:

e any expression;

v any expression to which a value can be assigned ("lvalue" expressions);

a an array;

f a function;

s a symbol —which is a variable, a constant or a function.

• Expressions

An expression consists of one or more operands with an operator. The operand can be a variable, a constant or another expression. An expression followed by a semicolon is a statement.

Listing: **examples of expressions**

```
v++
f(a1, a2)
v = (ia1 * ia2) / ia3
```

• Arithmetic

`+` `e1 + e2`
Results in the addition of `e1` and `e2`.

`-` `e1 - e2`
Results in the subtraction of `e1` and `e2`.

`-e`
Results in the arithmetic negation of a (two's complement).

`*` `e1 * e2`
Results in the multiplication of `e1` and `e2`.

`/` `e1 / e2`
Results in the division of `e1` by `e2`. The result is truncated to the nearest integral value that is less than or equal to the quotient. Both negative and positive values are rounded down, i.e. towards $-\infty$.

`%` `e1 % e2`
Results in the remainder of the division of `e1` by `e2`. The sign of the remainder follows the sign of `e2`. Integer division and remainder have the Euclidean property: `D = q*d + r`, where `q = D/d` and `r = D%d`.

`++` `v++`
increments `v` by 1; the result if the expression is the value of `v` *before* it is incremented.
`++v`
increments `v` by 1; the result if the expression is the value of `v` *after* it is incremented.

`--` `v--`
decrements `v` by 1; the result if the expression is the value of `v` *before* it is decremented.
`--v`
decrements `v` by 1; the result if the expression is the value of `v` *after* it is decremented.

Notes: The unary + is not defined in PAWN.
The operators `++` and `--` modify the operand. The operand must be an *lvalue*.

- **Bit manipulation**

`~` `~e`
results in the one's complement of `e`.

`>>` `e1 >> e2`
results in the *arithmetic* shift to the right of `e1` by `e2` bits. The shift operation is signed: the leftmost bit of `e1` is copied to vacant bits in the result.

`>>>` `e1 >>> e2`
results in the *logical* shift to the right of `e1` by `e2` bits. The shift operation is unsigned: the vacant bits of the result are filled with zeros.

`<<` `e1 << e2`
results in the value of `e1` shifted to the left by `e2` bits; the rightmost bits are set to zero. There is no distinction between an arithmetic and a logical left shift

`&` `e1 & e2`
results in the bitwise logical "and" of `e1` and `e2`.

`|` `e1 | e2`
results in the bitwise logical "or" of `e1` and `e2`.

`^` `e1 ^ e2`
results in the bitwise "exclusive or" of `e1` and `e2`.

• **Assignment**

The result of an assignment expression is the value of the left operand after the assignment. The left operand may not be tagged.

Tag names: 67

`=` `v = e`
assigns the value of `e` to variable `v`.

`=` `v = a`
assigns array `a` to variable `v`; `v` must be an array with the same size and dimensions as `a`; `a` may be a string or a literal array.

Note: the following operators combine an assignment with an arithmetic or a bitwise operation; the result of the expression is the value of the left operand after the arithmetic or bitwise operation.

`+=` `v += e`
increments `v` with `e`.

`-=` `v -= e`
decrements `v` with `e`

`*=` `v *= e`
multiplies `v` with `e`

`/=` `v /= e`
divides `v` by `e`.

`%=` `v %= e`
assigns the remainder of the division of `v` by `e` to `v`.

`>>=` `v >>= e`
shifts `v` arithmetically to the right by `e` bits.

`>>>=` `v >>>= e`
shifts `v` logically to the right by `e` bits.

`<<=` `v <<= e`
shifts `v` to the left by `e` bits.

`&=` `v &= e`
applies a bitwise "and" to `v` and `e` and assigns the result to `v`.

`|=` `v |= e`
applies a bitwise "or" to `v` and `e` and assigns the result to `v`.

`^=` `v ^= e`
applies a bitwise "exclusive or" to `v` and `e` and assigns the result to `v`.

• **Relational**

A logical "false" is represented by an integer value of 0; a logical "true" is represented by any value other than 0. Value results of relational expressions are either 0 or 1, and their tag is set to "`bool:`".

`==` `e1 == e2`
results in a logical "true" if `e1` is equal to `e2`.

`!=` `e1 != e2`
results in a logical "true" if `e1` differs from `e2`.

Note: the following operators may be "chained", as in the expression "`e1 <= e2 <= e3`", with the semantics that the result is "1" if *all* individual comparisons hold and "0" otherwise.

`<` `e1 < e2`
results in a logical "true" if `e1` is smaller than `e2`.

`<=` `e1 <= e2`
results in a logical "true" if `e1` is smaller than or equal to `e2`.

`>` `e1 > e2`
results in a logical "true" if `e1` is greater than `e2`.

`>=` `e1 >= e2`
results in a logical "true" if `e1` is greater than or equal to `e2`.

• **Boolean**

A logical "false" is represented by an integer value of 0; a logical "true" is represented by any value other than 0. Value results of Boolean expressions are either 0 or 1, and their tag is set to "bool".

`!` `!e`
results to a logical "true" if `e` was logically "false".

`||` `e1 || e2`
results to a logical "true" if either `e1` or `e2` (or both) are logically "true". The expression `e2` is only evaluated if `e1` is logically "false".

`&&` `e1 && e2`
results to a logical "true" if both `e1` and `e2` are logically "true". The expression `e2` is only evaluated if `e1` is logically "true".

• **Miscellaneous**

`[]` `a[e]`
array index: results to *cell* `e` from array a.

`{}` `a{e}`
array index: results to *character* `e` from "packed" array a.

`()` `f(e1,e2,...eN)`
results to the value returned by the function `f`. The function is called with the arguments `e1`, `e2`, ...`eN`. The order of evaluation of the arguments is undefined (an implementation may choose to evaluate function arguments in reversed order).

`? :` `e1 ? e2 : e3`
results in either `e2` or `e3`, depending on the value of `e1`. The conditional expression is a compound expression with a two part operator, "`?`" and "`:`". Expression `e2` is evaluated if `e1` is logically "true", `e3` is evaluated if `e1` is logically "false".

`:` *tagname*`: e`
tag override; the value of the expression `e` does not change, but its tag changes. See page 67 for more information.

`,` `e1, e2`
results in `e2`, `e1` is evaluated before `e2`. If used in function argument lists or a conditional expression, the comma expression must be surrounded by parentheses.

`defined` `defined s`
results in the value 1 if the symbol is defined. The symbol may be a constant (page 98), or a global or local variable. The tag of this expression is `bool:`.

Example: 77

`sizeof` `sizeof s`
results in the size in "elements" of the specified variable. For simple variables and for arrays with a single dimension, an element is a cell. For multi-dimensional arrays, the result is the number of array elements in that dimension —append `[]` to the array name to indicate a lower/more minor dimension. If the size of a variable is unknown, the result is zero.
When used in a default value for a function argument, the expression is evaluation at the point of the function call, instead of in the function definition.

`state` `state s`
where `s` is the name of a state that is optionally prefixed with the automaton name, this operator results in the value 1 if the automatons is in the indicated state and in 0 otherwise. The tag of this expression is `bool:`.

See also page 116 for state specifiers

`tagof` `tagof s`
results in the a unique number that represents the tag of the variable, the constant, the function result or the tag label. When used in a default value for a function argument, the expression is evaluation at the point of the function call, instead of in the function definition.

`char` `e char`
results the number of cells that are needed to hold a packed array of `e` characters.

• Operator precedence

The table beneath groups operators with equal precedence, starting with the operator group with the highest precedence at the top of the table.

If the expression evaluation order is not explicitly established by parentheses, it is determined by the association rules. For example: `a*b/c` is equivalent with `(a*b)/c` because of the left-to-right association, and `a=b=c` is equivalent with `a=(b=c)`.

`()`	function call	left-to-right
`[]`	array index (cell)	
`{}`	array index (character)	
`!`	logical not	right-to-left
`~`	one's complement	
`-`	two's complement (unary minus)	
`++`	increment	
`--`	decrement	
`:`	tag override	
`char`	convert number of packed characters to cells	
`defined`	symbol definition status	
`sizeof`	symbol size in "elements"	
`state`	automaton/state condition	
`tagof`	unique number for the tag	
`*`	multiplication	left-to-right
`/`	division	
`%`	remainder	
`+`	addition	left-to-right
`-`	subtraction	
`>>`	arithmetic shift right	left-to-right
`>>>`	logical shift right	
`<<`	shift left	
`&`	bitwise and	left-to-right
`^`	bitwise exclusive or	left-to-right
`|`	bitwise or	left-to-right
`<`	smaller than	left-to-right
`<=`	smaller than or equal to	
`>`	greater than	
`>=`	greater than or equal to	
`==`	equality	left-to-right
`!=`	inequality	
`&&`	logical and	left-to-right
`||`	logical or	left-to-right
`? :`	conditional	right-to-left
`=`	assignment	right-to-left
`*= /= %= += -= >>= >>>= <<= &= ^= |=`		
`,`	comma	left-to-right

Statements

A statement may take one or more lines, whereas one line may contain two or more statements.

Control flow statements (`if`, `if`–`else`, `for`, `while`, `do`–`while` and `switch`) may be nested.

Statement label

A label consists of an identifier followed by a colon ("`:`"). A label is a "jump target" of the `goto` statement.

Identifiers: 97

Each statement may be preceded by a label. There must be a statement after the label; an empty statement is allowed.

The scope of a label is the function in which it is declared (a `goto` statement cannot therefore jump out off the current function to another function).

Compound statement

A compound statement is a series of zero or more statements surrounded by braces (`{` and `}`). The final brace (`}`) should not be followed by a semicolon. Any statement may be replaced by a compound statement. A compound statement is also called a block. A compound statement with zero statements is a special case, and it is called an "empty statement".

Expression statement

Any expression becomes a statement when a semicolon ("`;`") is appended to it. An expression also becomes a statement when only white space follows it on the line and the expression cannot be extended over the next line.

Empty statement

An empty statement performs no operation and consists of a compound block with zero statements; that is, it consists of the tokens "`{ }`". Empty statements are used in control flow statements if there is no action (e.g. `while (!iskey()) {}`) or when defining a label just before the closing brace of a compound statement. An empty statement does not end with a semicolon.

assert *expression*

Aborts the program with a run-time error if the expression evaluates to logically "false".

Example: 9

break

Example: 19

Terminates and exits the smallest enclosing `do`, `for` or `while` statement from any point within the loop other than the logical end. The `break` statement moves program control to the next statement outside the loop.

continue

Terminates the current iteration of the smallest enclosing `do`, `for` or `while` statement and moves program control to the condition part of the loop. If the looping statement is a `for` statement, control moves to the third expression in the `for` statement (and thereafter to the second expression).

do *statement* **while (** *expression* **)**

Example: 26

Executes a statement before the condition part (the `while` clause) is evaluated. The statement is repeated while the condition is logically "true". The statement is at least executed once.

exit *expression*

Abort the program. The expression is optional, but it must start on the same line as the `exit` statement if it is present. The `exit` instruction returns the expression value (plus the expression tag) to the host application, or zero if no exit expression is present. The significance and purpose of exit codes is implementation defined.

for (*expression 1* **;** *expression 2* **;** *expression 3* **)** *statement*

Examples: 7, 9, 19

All three expressions are optional.

Variable declarations: 61

expression 1 Evaluated only once, and before entering the loop. This expression may be used to initialize a variable.

This expression may also hold a variable declaration, using the `new` syntax. A variable declared in this expression exists only in the `for` loop.

You cannot combine and expression (using already existing variables) and a declaration of new variables in this field —either all variables in this field must already exist, or they must all be created in this field.

expression 2 Evaluated before each iteration of the loop and ends the loop if the expression results to logically "false".

If omitted, the result of expression 2 is assumed to be logically "true".

expression 3 Evaluated after each execution of the statement. Program control moves from expression 3 to expression 2 for the next (conditional) iteration of the loop.

The statement `for( ; ; )` is equivalent with `while (true)`.

goto *label*

Moves program control (unconditionally) to the statement that follows the specified label. The label must be within the same function as the goto statement (a goto statement cannot jump out of a function).

if (*expression* **)** *statement 1* **else** *statement 2*

Executes statement 1 if the expression results to logically "true". The `else` clause of the `if` statement is optional. If the expression results to logically "false" and an `else` clause exists, the statement associated with the `else` clause (statement 2) executes.

Example: 5

When `if` statements are nested and `else` clauses are present, a given `else` is associated with the closest preceding `if` statement in the same block.

return *expression*

Terminates the current function and moves program control to the statement following the calling statement. The value of the expression is returned as the function result. The expression may be an array variable or a literal array.

Examples: 9, 19

The expression is optional, but it must start on the same line as the `return` statement if it is present. If absent, the value of the function is zero.

sleep *expression*

Abort the program, but leave it in a re-startable state. The expression is optional. If included, the `sleep` instruction returns the expression value (plus the expression tag) to the host application. The significance and purpose of exit codes/tags is implementation defined; typically, an application uses the `sleep` instruction to allow for light-weight multi-tasking of several concurrent PAWN programs, or to implement "latent" functions.

state (*expression*) **automaton** :*name*

Changes the current state in the specified automaton. The expression between parentheses is optional; if it is absent, the parentheses must be omitted as well. The name of the automaton is optional as well, when changing the state of the default, anonymous, automaton; if the automaton name is absent, the colon (":") must be omitted as well.

Below are two examples of *unconditional* state changes. The first is for the default automaton:

```
state handshake
```

and the second for a specific automaton:

```
state gps:handshake
```

See page 39 for examples of conditional state changes

Often, whether or not a state changes depends on parameters of the event or the condition of the automaton as a whole. Since conditional state changes are so frequent, the condition may be in the `state` instruction itself.* The condition follows the keyword `state`, between parentheses. The state will *only* change if the condition is logically "true".

"entry" functions: 43, "exit" functions: 45

The `state` instruction causes an implied call to the `exit` function of the current state and to the `entry` function for the new state —if such `exit` and `entry` functions exist.

switch (*expression*) { *case list* }

Transfers control to different statements within the switch body depending on the value of the switch expression. The body of the `switch` statement is a compound statement, which contains a series of "case clauses".

Each "case clause" starts with the keyword `case` followed by a constant list and *one* statement. The constant list is a series of expressions, separated by comma's, that each evaluates to a constant value. The constant list ends with a colon. To specify a "range" in the constant list, separate the lower and upper bounds of the range with a double period ("`..`"). An example of a range is: "`case 1..9:`".

* The alternative is to fold *un*conditional state changes in the common if–else construct.

The `switch` statement moves control to a "case clause" if the value of one of the expressions in the constant list is equal to the `switch` expression result.

The "default clause" consists of the keyword `default` and a colon. The default clause is optional, but if it is included, it must be the last clause in the switch body. The `switch` statement moves control to the "default clause" if none of the case clauses match the expression result.

Example:

```
switch (weekday(12,31,1999))
    {
    case 0, 1:          /* 0 == Saturday, 1 == Sunday */
        print("weekend")
    case 2:
        print("Monday")
    case 3:
        print("Tuesday")
    case 4:
        print("Wednesday")
    case 5:
        print("Thursday")
    case 6:
        print("Friday")
    default:
        print("invalid week day")
    }
```

while (*expression*) *statement*

Evaluates the expression and executes the statement if the expression result yields logically "true". After the statement has executed, program control returns to the expression again. The statement is thus executed while the expression is true.

Examples: 5, 19, 24

Directives

All directives must appear first on a line (they may be preceded by white space, but not by any other characters). All directives start with the character `#` and the complete instruction may not span more than one line.

#assert *constant expression*

Issues a compile time error if the supplied constant expression evaluates to zero. The `#assert` directive is most useful to guard against implementation defined constructs on which a program may depend, such as the cell size in bits, or the number of packed characters per cell.

See also "Predefined constants" on page 103

#define *pattern replacement*

Defines a text substitution macro. The pattern is matched to all lines read from the source files; the sections that match are replaced by the replacement texts. The pattern and the replacement texts may contain parameters, denoted by "`%0`" to "`%9`". See page 93 for details and examples on text substitution.

#endinput

Closes the current file and thereby ignores all the text below the `#endinput` directive.

#error

message: Signals a "user error" with the specified message. User errors are fatal errors and they serve a similar purpose as the `#assert` directive.

#file *name*

Adjusts the name for the current file. This directive is used implicitly by the text preprocessor; there is usually no need to set a filename explicitly.

#if *constant expression*, **#elseif, #else, #endif**

Portions of a program may be parsed or be ignored depending on certain conditions. The PAWN parser (compiler or interpreter) generates code only for those portions for which the condition is true.

The directive `#if` must be followed by a constant expression. To check whether a variable or constant is defined, use the `defined` operator.

Zero or more `#elseif` directives may follow the initial `#if` directive. These blocks are skipped if any of the preceding `#if` or `#elseif` blocks were parsed (i.e. not skipped). As with the `#if` directive, a constant expression must follow the `#elseif` expression.

The `#else` causes the parser to skip all lines up to `#endif` if the preceding `#if` or any of the preceding `#elseif` directives were "true", and the parses these lines if all preceding blocks were skipped. The `#else` directive may be omitted; if present, there may be only be one `#else` associated with each `#if`.

The `#endif` directive terminates a program portion that is parsed conditionally. Conditional directives can be nested and each `#if` directive must be ended by an `#endif` directive.

#include *filename* **or** *<filename>*

Inserts the contents of the specified file at the current position within the current file. A filename between angle brackets ("<" and ">") refers to a system file; the PAWN parser (compiler or interpreter) will search for such files only in a pre-set list of directories and not in the "current" directory. Filenames that are unquoted or that appear in double quotes are normal include files, for which a PAWN parser will look in the current directory first.

The PAWN parser first attempts to open the file with the specified name. If that fails, it tries appending the extensions "`.inc`", "`.p`" and "`.pawn`" to the filename (in that order). The proposed default extension of include files is "`.inc`".

When the file can be opened successfully, the `#include` directive defines a constant with the name "`_inc_`" plus the base name of the file (the filename without path and extension) and the value 1. If the constant already exists, the `#include` directive skips opening and including the file, thus preventing a double inclusion. To force a double include, remove the constant definition with the `#undef` directive before the second inclusion of the file.

#line *number*

The current line number (in the current file). This directive is used implicitly by the text preprocessor; there is usually no need to set the line number explicitly.

#pragma *extra information*

A "pragma" is a hook for a parser to specify additional settings, such as warning levels or extra capabilities. Common `#pragma`s are:

`#pragma align`

Aligns the next declaration to the offset set with the alignment compiler option. Some (native) functions may perform better with parameters that are passed by reference when these are on boundaries of 8, 16, or even 32 bytes. Alignment requirements are dependent of the host applications.

Putting the `#pragma align` line in front of a declaration of a global or a static variable aligns this variable to the boundary set with the compiler option. This `#pragma` aligns only the variable that immediately follows the `#pragma`. The alignment of subsequent variables depends on the size and alignment of the variables that precede it. For example, if a global array variable of 2 cells is aligned on a 16-byte boundary and a cell is 4 bytes, the next global variable is located 8 bytes further.

Putting the `#pragma align` line in front of a declaration of a function will align the stack frame of that function to the boundary specified earlier, with the result that the first local, non-"static", variable is aligned to that boundary. The alignment of subsequent variables depends on the size and alignment of the variables that precede it. In practice, to align a local non-static variable, you must align the function's stack frame and declare that variable before any other variables.

`#pragma amxlimit` *value*

Sets the *maximum* size, in bytes, that the compiled script may grow to. This pragma is useful for (embedded) environments where the maximum size of a script is bound to a hard upper limit.

If there is no setting for the amount of RAM for the data and stack (see the pragma `amxram`), this refers to the total memory requirements; if the amount of RAM is explicitly set, this value only gives the amount of memory needed for the code and the static data.

`#pragma amxram` *value*

Sets the *maximum* memory requirements, in bytes, for data and stack that a compiled script may have. This value is is useful for (embedded) environments where the maximum data size of a script is bound to a hard upper limit. Especially in the case where the PAWN script runs from ROM, the sizes for the code and data sections need both to be set.

`#pragma codepage` *name/value*

The PAWN parser can translate characters in character constants and in *unpacked* strings to Unicode/UCS-4 "wide" characters. This `#pragma` indicates the codepage that must be used for the translation. See the section "Internationalization" on page 139 for details and required extra resources for the codepage translation.

`#pragma compress` *value*

The PAWN parser may write the generated P-code in compact or plain ("non-compact") encoding. The default depends on the parser configuration (and, perhaps, user settings). This `#pragma` allows the script writer to override the default and force compact encoding (when *value* is non-zero) or to force plain encoding (when *value* is zero). Especially toggling compact encoding off (forcing plain encoding) is useful, because the PAWN parser may be unable to compile a particular script in "compact encoding" mode.

`#pragma ctrlchar` *character*

Defines the character to use to indicate the start of a "escape sequence". By default, the control character is "\".

Escape character: 100

For example

```
#pragma ctrlchar '$'
```

You may give the new value for the control character as a character constant (between single quotes) or as a decimal or hexadecimal value. When you omit the value of the new control character, the parser reverts to the default control character.

`#pragma deprecated` *value*

The subsequent symbol is flagged as "deprecated". If a

script uses it, the parser issues a warning.

`#pragma dynamic` *value*
: Sets the size, in cells, of the memory block for dynamic data (the stack and the heap) to the value specified by the expression. The default size of the dynamic data block is implementation defined. An implementation may also choose to grow the block on an as-needed basis (see the host program's documentation, or the "Implementer's Guide" for details).

`#pragma library` *name*
: Sets the name of the (dynamically linked) extension module that contains required native functions. This `#pragma` should appear above native function declarations that are part of the extension module.

  The library *name* parameter may be absent, in which case any subsequent native function declarations are not associated with *any* extension module.

  The scope of this `#pragma` runs from the line at which it appears until the end of the file in which it appears. In typical usage, a `#pragma library` line will appear at the top of an include file that declares native functions for an extension module, and the scope of the library "link" ends at the end of that include file.

`#pragma overlay` *value*
: The PAWN parser can generate P-code that runs as dynamically loaded overlays. Currently, an overlay is the size of a function. Whether the parser generates P-code for overlaid execution or for standard execution depends on the parser configuration (and, perhaps, user settings). This `#pragma` allows the script writer to override the default. The parameter of this `#pragma` is the size of the overlay pool in bytes, or zero to turn overlay support off.

`#pragma pack` *value*
: If *value* is zero, packed literal strings start with "`!"`" (exclamation point + double quote) and unpacked literal strings with only a double quote ("`"`"), as described in this manual at page 100. If `value` is non-zero, the syntax for packed and

unpacked literal strings is swapped: literal strings that start with a double quote are packed and literal strings that start with "`!"`" are unpacked.

`#pragma rational` *tagname*(*value*)

Enables support for rational numbers. The `tagname` is the name of the tag that rational numbers will have; typically one chooses the names "`Float:`" or "`Fixed:`". The presence of *value* in parentheses behind *tagname* is optional: if it is omitted, a rational number is stored as a "floating point" value according to the IEEE 754 norm; if it is present, a rational number is a fixed precision number ("scaled integer") with the specified number of decimals.

Rational number support: 99

`#pragma semicolon` *value*

If *value* is zero, no semicolon is required to end a statement if that statement is last on a line. Semicolons are still needed to separate multiple statements on the same line.

When semicolons are optional (the default), a postfix operator (one of "`++`", "`--`" and "`char`") may not be the first token on a line, as they will be interpreted as prefix operators.

`#pragma tabsize` *value*

The number of characters between two consecutive TAB positions. The default value is 8. You may need to set the TAB size to avoid warning 217 (loose indentation) if the source code is indented alternately with spaces and with TAB characters. Alternatively, by setting the "`tabsize`" `#pragma` to zero, the parser will no longer issue warning 217.

`#pragma unused` *symbol,...*

Marks the named symbol as "used". Normally, the PAWN parser warns about unused variables and unused local constants. In most situations, these variables and constants are redundant, and it is better to remove them for the sake of code clarity. Especially in the case of local constants, it may, however, be better (or required) to keep the constant definitions. This `#pragma` then permits to mark the symbol (variable or constant) as "used", and avoid a parser warning.

Warning messages: 162

The `#pragma` must appear *after* the symbol declaration — but it need not appear immediately after the declaration.

Multiple symbol names may appear in a single `#pragma`; the symbols must be separated by commas.

#section *name*

Starts a new section for the generated code. Any variables and functions that are declared "`static`" are only visible to the section to which they belong. By default, each source file is a separate section and there is only one section per file.

With the `#section` directive, you can create multiple sections in a source file. The name of a section is optional, if it is not set, a unique identifier for the source file is used for the name of the section.

Any declared section ends automatically at the end of the file.

#tryinclude *filename* **or** <*filename*>

This directive behaves similarly as the `#include` directive, but it does not give an error when the file to include does not exist —i.e., try to include but fail silently on error.

#undef *name*

Removes a text substitution macro or a numeric constant declared with `const`. The "name" parameter must be the macro "prefix" —the alphanumeric part of the macro. See page 93 for details and examples on text substitution.

Proposed function library

Since PAWN is targeted as an application extension language, most of the functions that are accessible to PAWN programs will be specific to the host application. Nevertheless, a small set of functions may prove useful to many environments.

• Core functions

The "core" module consists of a set of functions that support the language itself. Several of the functions are needed to pull arguments out of a variable argument list (see page 80).

---

clamp — Force a value inside a range

Syntax: `clamp(value, min=cellmin, max=cellmax)`

`value`	The value to force in a range.
`min`	The low bound of the range.
`max`	The high bound of the range.

Returns: `value` if it is in the range `min` – `max`; `min` if `value` is lower than `min`; and `max` if `value` is higher than `max`.

See also: `max`, `min`

---

funcidx — Return a public function index

Syntax: `funcidx(const name[])`

Returns: The index of the named public function. If no public function with the given name exists, `funcidx` returns −1.

Notes: A host application runs a public function from the script by passing the public function's index to `amx_Exec`. With this function, the script can query the index of a public function, and thereby return the "next function to call" to the application.

amx_Exec: see the "Implementer's Guide"

getarg Get an argument

Syntax: `getarg(arg, index=0)`

`arg` The argument sequence number, use 0 for first argument.

`index` The index, in case `arg` refers to an array.

Returns: The value of the argument.

Notes: This function retrieves an argument from a variable argument list. When the argument is an array, the `index` parameter specifies the index into the array. The return value is the retrieved argument.

See also: `numargs`, `setarg`

heapspace Return free heap space

Syntax: `heapspace()`

Returns: The free space on the heap. The stack and the heap occupy a shared memory area, so this value indicates the number of bytes that is left for either the stack or the heap.

Notes: In absence of recursion, the PAWN parser can also give an estimate of the required stack/heap space.

max Return the highest of two numbers

Syntax: `max(value1, value2)`

`value1`
`value2` The two values for which to find the highest number.

Returns: The higher value of `value1` and `value2`.

See also: `clamp`, `min`

min Return the lowest of two numbers

Syntax: `min(value1, value2)`

`value1`
`value2` The two values for which to find the lowest number.

Returns: The lower value of `value1` and `value2`.

See also: `clamp`, `max`

numargs Return the number of arguments

Syntax: `numargs()`

Returns: The number of arguments passed to a function; `numargs` is useful inside functions with a variable argument list.

See also: `getarg`, `setarg`

random Return a pseudo-random number

Syntax: `random(max)`

`max` The limit for the random number.

Returns: A pseudo-random number in the range `0` – `max-1`.

Notes: The standard random number generator of PAWN is likely a linear congruential pseudo-random number generator with a range and a period of 2^{31}. Linear congruential pseudo-random number generators suffer from serial correlation (especially in the low bits) and it is unsuitable for applications that require high-quality random numbers.

setarg Set an argument

Syntax: `setarg(arg, index=0, value)`

`arg`	The argument sequence number, use 0 for first argument.
`index`	The index, in case `arg` refers to an array.
`value`	The value to set the argument to.

Returns: `true` on success and `false` if the argument or the index are invalid.

Notes: This function sets the value of an argument from a variable argument list. When the argument is an array, the `index` parameter specifies the index into the array.

See also: `getarg`, `numargs`

swapchars Swap bytes in a cell

Syntax: `swapchars(c)`

`c`	The value for which to swap the bytes.

Returns: A value where the bytes in parameter "`c`" are swapped (the lowest byte becomes the highest byte).

tolower Convert a character to lower case

Syntax: `tolower(c)`

`c`	The character to convert to lower case.

Returns: The upper case variant of the input character, if one exists, or the unchanged character code of "`c`" if the letter "`c`" has no lower case equivalent.

Notes: Support for accented characters is platform-dependent.

See also: `toupper`

toupper Convert a character to upper case

Syntax: `toupper(c)`

`c` The character to convert to upper case.

Returns: The lower case variant of the input character, if one exists, or the unchanged character code of "`c`" if the letter "`c`" has no upper case equivalent.

Notes: Support for accented characters is platform-dependent.

See also: `tolower`

❖

Properties are general purpose names or values. The property list routines maintain a list of these name/value pairs that is shared among all abstract machines. The property list is therefore a way for concurrent abstract machines to exchange information.

All "property maintenance" functions have an optional "id" parameter. You can use this parameter to indicate which abstract machine the property belongs to. (A host application that supports concurrent abstract machines will usually provide each abstract machine with a unique id.) When querying (or deleting) a property, the id value that you pass in is matched to the id values of the list.

A property is identified with its "abstract machine id" plus *either* a name *or* a value. The name-based interface allows you to attach a value (e.g. the handle of an object) to a name of your choosing. The value-based interface allows you to attach a string to a number. The difference between the two is basically the search key versus the output parameter.

All property maintenance functions have a "name" and a "value" parameter. Only one of this pair must be filled in. When you give the value, the `getproperty` function stores the result in the `string` argument and the `setproperty` function reads the string to store from the `string` argument.

The number of properties that you can add is limited only by available memory.

getproperty(id=0, const name[]="", value=cellmin, string[]="")
Returns the value of a property when the `name` is passed in; fills in the `string` argument when the `value` is passed in. The `name` string may either be a packed or an unpacked string. If the property does not exist, this function returns zero.

setproperty(id=0, const name[]="", value=cellmin, const string[]="")
Add a new property or change an existing property.

deleteproperty(id=0, const name[]="", value=cellmin)
Returns the value of the property and subsequently removes it. If the property does not exist, the function returns zero.

existproperty(id=0, const name[]="", value=cellmin)
Returns `true` if the property exists and `false` otherwise.

• Console functions

For testing purposes, the console functions that read user input and that output strings in a scrollable window or on a standard terminal display are often convenient. Not all terminal types and implementations may implement all functions —especially the functions that clear the screen, set foreground and background colours and control the cursor position, require an extended terminal control.

getchar(echo=true)
Read one character from the keyboard and return it. The function can optionally echo the character on the console window.

getstring(string[], size=sizeof string, bool
pack=false): Read a string from the keyboard. Function `getstring` stops reading when either the enter key is typed, or the maximum length is reached. The maximum length is in *cells* (not characters) and it includes a terminating null character. The function can read both packed and unpacked strings; when reading a packed string, the function may read more *characters* than the `size` parameter specifies, because each cell holds multiple characters. The return value is the number of *characters* read, excluding the terminating null character.

getvalue(base=10, end='\r', ...)
Read a value (a signed number) from the keyboard. The `getvalue`

function allows you to read in a numeric radix from 2 to 36 (the `base` parameter) with decimal radix by default.

By default the input ends when the user types the enter key, but one or more different keys may be selected (the `end` parameter and subsequent). In the list of terminating keys, a positive number (like `'\r'`) displays the key and terminates input, and a negative number terminates input without displaying the terminating key.

print(const string[], foreground=-1, background=-1)

Prints a simple string on the console. The foreground and background colours may be optionally set (but note that a terminal or a host application may not support colours). See `setattr` below for a list of colours.

printf(const format[], ...)

Prints a string with embedded codes:

- `%b` print a number at this position in binary radix
- `%c` print a character at this position
- `%d` print a number at this position in decimal radix
- `%f` print a floating point number at this position (assuming floating point support is present)
- `%q` print a fixed point number at this position (assuming fixed point support is present)
- `%r` print either a floating point number or a fixed point number at this position, depending on what is available; if both floating point and fixed point support is present, `%r` is equivalent to `%f` (i.e. printing a floating point number)
- `%s` print a character string at this position
- `%x` print a number at this position in hexadecimal radix

The `printf` function works similarly to the `printf` function of the C language.

clrscr()

Clears the console and sets the cursor in the upper left corner.

clreol()

Clears the line at which the cursor is, from the position of the cursor to the right margin of the console. This function does not move the cursor.

gotoxy(x=1, y=1)
: Sets the cursor position on the console. The upper left corner is at (1,1). The function returns `false` if the requested position is invalid.

setattr(foreground=-1, background=-1)
: Sets foreground and background colours for the text written onto the console. When either of the two parameters is negative (or absent), the respective colour setting will not be changed. The colour value must be a value between zero and seven, as per the ANSI Escape sequences, ISO 6429. Predefined constants for the colours are `black` (0), `red` (1), `green` (2), `yellow` (3), `blue` (4), `magenta` (5), `cyan` (6) and `white` (7).

- **Date/time functions**

Functions to get and set the current date and time, as well as a millisecond resolution "event" timer are described in an application note entitled "Time Functions Library" that is available separately.

- **File input/output**

Functions for handling text and binary files, with direct support for UTF-8 text files, is described in an application note entitled "File I/O Support Library" that is available separately.

- **Fixed point arithmetic**

The fixed-point decimal arithmetic module for PAWN is described in an application note entitled "Fixed Point Support Library" that is available separately.

- **Floating point arithmetic**

The floating-point arithmetic module for PAWN is described in an application note entitled "Floating Point Support Library" that is available separately.

- **Process and library call interface**

Functions to launch and control external applications and functions to use general purpose DLLs or shared libraries is described in an application note entitled "Process control and Foreign Function Interface" that is available separately.

- **String manipulation**

A general set of string manipulation functions, operating on both packed and unpacked strings, is described in an application note entitled "String Manipulation Library" that is available separately.

Pitfalls: differences from C

◇ PAWN lacks the typing mechanism of C. PAWN is an "integer-only" variety of C; there are no structures or unions, and floating point support must be implemented with user-defined operators and the help of native functions.

◇ The accepted syntax for rational numbers is stricter than that of floating point values in C. Values like ".5" and "6." are acceptable in C, but in PAWN one must write "0.5" and "6.0" respectively. In C, the decimal period is optional if an exponent is included, so one can write "2E8"; PAWN does not accept the upper case "E" (use a lower case "e") and it requires the decimal point: e.g. "2.0e8". See page 99 for more information.

◇ PAWN does not provide "pointers". For the purpose of passing function arguments by reference, PAWN provides a "reference" argument, (page 71). The "placeholder" argument replaces some uses of the NULL pointer (page 75).

◇ Numbers can have hexadecimal, decimal or binary radix. Octal radix is not supported. See "Constants" on page 98. Hexadecimal numbers must start with "`0x`" (a lower case "x"), the prefix "`0X`" is invalid.

◇ Escape sequences ("`\n`", "`\t`", etc.) are the same, except for "`\ddd`" where "`ddd`" represent three *decimal* digits, instead of the *octal* digits that C/C++ uses. The backslash ("\") may be replaced with another symbol; see `#pragma ctrlchar` on page 121 —notably, previous versions of PAWN used the caret ("`^`") as the escape character.

◇ Cases in a `switch` statement are *not* "fall through". Only a single instruction may (and must) follow each `case` label. To execute multiple instructions, you must use a compound statement. The `default` clause of a `switch` statement must be the last clause of the `switch` statement. More on page 116. In C/C++, `switch` is a "conditional goto", akin to Fortran's calculated labels. In PAWN, `switch` is a structured "if".

◇ A `break` statement breaks out of loops only. In C/C++, the `break` statement also ends a `case` in a `switch` statement. Switch statements are implemented differently in PAWN (see page 116).

◇ PAWN supports "array assignment", with the restriction that both arrays must have the same size. For example, if "`a`" and "`b`" are both arrays with 6 cells, the expression "`a = b`" is valid. Next to literal strings, PAWN

also supports literal arrays, allowing the expression "`a = {0,1,2,3,4,5}`" (where "`a`" is an array variable with 6 elements).

◇ `char` is an operator, not a type. See page 111 and the tips on page 137.

◇ `defined` is an operator, not a preprocessor directive. The `defined` operator in PAWN operates on constants (with `const` and `enum`), global variables, local variables and functions.

◇ The `sizeof` operator returns the size of a variable in "elements", not in "bytes". An element may be a cell or a sub-array. See page 110 for details.

◇ The empty instruction is an empty compound block, not a semicolon (page 113). This modification avoids a frequent error.

◇ The compiler directives differ from C's preprocessor commands. Notably, the `#define` directive is incompatible with that of C/C++, and `#ifdef` and `#ifndef` are replaced by the more general `#if` directive (see "Directives" on page 118). To create numeric constants, see also page 102; to create string constants, see also page 93.

◇ Text substitutions (preprocessor macros; see the `#define` directive) are not matched *across* lines. That is, the text that you want to match and replace with a `#define` macro *must* appear on a single line. The definition of a `#define` macro must also appear on a single line.

◇ The direction for truncation for the operator "`/`" is always towards the smaller value, where -2 is smaller than -1. The "`%`" operator always gives a positive result, regardless of the signs of the operands. See page 105.

◇ There is no unary "`+`" operator, which is a "no-operation" operator anyway.

◇ Three of the bitwise operators have different precedence than in C. The precedence levels of the "`&`", "`^`" and `|` operators is higher than the relational operators (Dennis Ritchie explained that these operators got their low precedence levels in C because early C compilers did not yet have the logical "`&&`" and `||` operators, so the bitwise "`&`" and `|` were used instead).

◇ The "extern" keyword does not exist in PAWN; the current implementation of the compiler has no "linking phase". To create a program from several source files, add all source files the compilers command line, or create one main project script file that "`#include`'s" all other source files. The PAWN compiler can optimize out functions and global variables that you do not use. See pages 62 and 84 for details.

◇ In most situations, forward declarations of functions (i.e., prototypes) are not necessary. PAWN is a two-pass compiler, it will see all functions on the first pass and use them in the second pass. User-defined operators must be declared before use, however.

If provided, forward declarations must match *exactly* with the function definition, parameter names may not be omitted from the prototype or differ from the function definition. PAWN cares about parameter names in prototypes because of the "named parameters" feature. One uses prototypes to call forwardly declared functions. When doing so with named parameters, the compiler must already know the names of the parameters (and their position in the parameter list). As a result, the parameter names in a prototype must be equal to the ones in the definition.

Assorted tips

• Working with characters and strings

Strings can be in packed or in unpacked format. In the packed format, each cell will typically hold four characters (in common implementations, a cell is 32-bit and a character is 8 bit). In this configuration, the first character in a "pack" of four is the highest byte of a cell and the fourth character is in the lowest byte of each cell.

A string must be stored in an array. For an unpacked string, the array must be large enough to hold all characters in the string plus a terminating zero cell. That is, in the example below, the variable `ustring` is defined as having five cells, which is just enough to contain the string with which it is initialized:

Listing: **unpacked string**

```
new ustring[5] = "test"
```

In a packed string, each cell contains several characters and the string ends with a zero character. The `char` operator helps with declaring the array size to contain the required number of *characters*. The example below will allocate enough cells to hold five packed characters. In a typical implementation, there will be two cells in the array.

Listing: **packed string**

```
new pstring[5 char] = !"test"
```

In other words, the `char` operators divides its left operand by the number of bytes that fit in a cell and rounds upwards. Again, in a typical implementation, this means dividing by four and rounding upwards.

You can design routines that work on strings in both packed and unpacked formats. To find out whether a string is packed or unpacked, look at the first cell of a string. If its value is either negative or higher than the maximum possible value of an unpacked character, the string is a packed string. Otherwise it is an unpacked string.

See the separate application note for proposed native functions that operate on both packed and unpacked strings

The code snippet below returns `true` if the input string is packed and `false` otherwise:

Listing: **ispacked function**

```
bool: ispacked(string[])
    return !(0 <= string[0] <= ucharmax)
```

An unpacked string ends with a full zero cell. The end of a packed string is marked with only a zero character. Since there may be up to four characters in a 32-bit cell, this zero character may occur at any of the four positions in the "pack". The `{ }` operator extracts a character from a cell in an array. Basically, one uses the cell index operator ("`[ ]`") for unpacked strings and the character index operator ("`{ }`") to work on packed strings.

EOS: predefined constant standing for End Of String; it has the value '\0'

For example, a routine that returns the length in characters of any string (packed or unpacked) is:

Listing: **my_strlen function**

```
my_strlen(string[])
    {
    new len = 0
    if (ispacked(string))
        while (string{len} != EOS)      /* get character from pack */
            ++len
    else
        while (string[len] != EOS)      /* get cell */
            ++len
    return len
    }
```

If you make functions to work exclusively on either packed or unpacked strings, it is a good idea to add an assertion to enforce this condition:

Listing: **strupper function**

```
strupper(string[])
    {
    assert ispacked(string)

    for (new i=0; string{i} != EOS; ++i)
        string{i} = toupper(string{i})
    }
```

Predefined constants: 103

Although, in preceding paragraphs we have assumed that a cell is 32 bits wide and a character is 8 bits, this should not be relied upon. The size of a cell is implementation defined; the maximum and minimum values are in the predefined constants `cellmax` and `cellmin`. There are similar predefined constants for characters. One may safely assume, however, that both the size of a character in bytes and the size of a cell in bytes are powers of two.

The `char` operator allows you to determine how many packed characters fit in a cell. For example:

```
#if     4 char == 1
    /* code that assumes 4 packed characters per cell */
#elseif 4 char == 2
    /* code that assumes 2 packed characters per cell */
#elseif 4 char == 4
    /* code that assumes 1 packed character per cell */
#else
    #assert 0 /* unsupported cell/character size */
#endif
```

• Internationalization

Programming examples in this manual have used the English language for all output (prompts, messages, ...), and a Latin character set. This is not necessarily so; one can, for example, modify the first "hello world" program on page 3 to:

Listing: **"hello world" in Greek**

```
main()
    printf "Γειὰσου κὸσμος\n"
```

PAWN has basic support for non-Latin alphabets, but it only accepts non-Latin characters in strings and character constants. The PAWN language requires that all keywords and symbols (names of functions, variables, tags and other elements) be encoded in the ASCII character set.

For languages whose required character set is relatively small, a common solution is to use an 8-bit extended ASCII character set (the ASCII character set is 7-bit, holding 128 characters). The upper 128 codes of the extended set contain glyphs specific for the language. For Western European languages, a well known character set is "Latin-1", which is standardized as ISO 8859-1 —the same set also goes by the name "codepage 1252", at least for Microsoft Windows.* Codepages have been defined for many languages; for example, ISO 8859-2 ("Latin-2") has glyphs used in Central and Eastern Europe, and ISO 8859-7 contains the Greek alphabet in the upper half of the extended ASCII set.

Unfortunately, codepage selection can by confusing, as vendors of operating systems typically created their own codepages irrespective of what already existed. As a result, for most character sets there exist multiple incompatible

* Codepage 1252 is *not* exactly the same as Latin-1; Microsoft extended the standardized set to include glyphs at code positions that Latin-1 marks as "reserved".

codepages. For example, codepage 1253 for Microsoft Windows also encodes the Greek alphabet, but it is incompatible with ISO 8859-7. When writing texts in Greek, it now becomes important to check what encoding is used, because many Microsoft Windows applications support both.

When the character set for a language exceeds 256 glyphs, a codepage does not suffice. Traditionally, the codepage technique was extended by reserving special "shift" codes in the base character set that switch to a new set of glyphs. The next character then indicates the specific glyph. In effect, the glyph is now identified by a 2-byte index. On the other hand, some characters (especially the 7-bit ASCII set) can still be indicated by a single byte. The "Shift-JIS" standard, for the Japanese character set, is an example for the variable length encoding.

Codepages become problematic when interchanging documents or data with people in regions that use a different codepage, or when using different languages in the same document. Codepages that use "shift" characters complicate the matter further, because text processing must now take into account that a character may take either one or two bytes. Scanning through a string from right to left may even become impossible, as a byte may either indicate a glyph from the base set ("unshifted") or it may be a glyph from a shifted set —in the latter case the preceding byte indicates the shift set, but the meaning of the preceding character depends on the character before *that*.

The ISO/IEC 10646 "Universal Character Set" (UCS) standard has the ambitious goal to eventually include all characters used in all the written languages in the world, using a 31-bit character set. This solves both of the problems related to codepages and "shifted" character sets. However, the ISO/IEC body could not produce a standard in time, and therefore a consortium of mainly American software manufacturers started working in parallel on a simplified 16-bit character set called "Unicode". The rationale behind Unicode was that it would encode *abstract characters*, not *glyphs*, and that therefore 65,536 would be sufficient.[†] In practice, though, Unicode *does* encode glyphs and not long after it appeared, it became apparent that 65,536 code points would not be enough. To counter this, later Unicode versions were extended with multiple "planes" and special codes that select a plane. The combination of a plane selector and the code pointer inside that plane

[†] If Unicode encodes *characters*, an "Unicode font" is a contradictio in terminis —because a font encodes glyphs.

is called a "surrogate pair". The first 65,536 code points are in the "Basic Multilingual Plane" (BMP) and characters in this set do not need a plane selector.

Essentially, the introduction of surrogate pairs in the Unicode standard is equivalent to the shift codes of earlier character sets —and it carries some of the problems that Unicode was intended to solve. The UCS-4 encoding by ISO/IEC 10646 does *not* have/need surrogate pairs.

Support for Unicode/UCS-4 in (host) applications and operating systems has emerged in two different ways: either the internal representation of characters is multi-byte (typically 16-bit, or 2-byte), or the application stores strings internally in UTF-8 format, and these strings are converted to the proper glyphs only when displaying or printing them. Recent versions of Microsoft Windows use Unicode internally; The Plan-9 operating system pioneered the UTF-8 encoding approach, which is now widely used in Unix/ Linux. The advantage of UTF-8 encoding as an internal representation is that it is *physically* an 8-bit encoding, and therefore compatible with nearly all existing databases, file formats and libraries. This circumvents the need for double entry-points for functions that take string parameters —as is the case in Microsoft Windows, where many functions exist in an "A"NSI and a "W"ide version. A disadvantage of UTF-8 is that it is a variable length encoding, and many in-memory string operations are therefore clumsy (and inefficient). That said, with the appearance of surrogate pairs, Unicode has now also become a variable length encoding.

The PAWN language requires that its keywords and symbols names are in ASCII, and it allows non-ASCII characters in strings. There are five ways that a host application could support non-ASCII characters in strings and character literals:

1 Support codepages: in this strategy the entire complexity of choosing the correct glyphs and fonts is delegated to the host application. The codepage support is based on codepage mapping files with a file format of the "cross mapping tables" distributed by the Unicode consortium.

2 Support Unicode or UCS-4 and let the PAWN compiler convert scripts that were written using a codepage to "wide" characters: for this strategy, you need to set `#pragma codepage` or use the equivalent compiler option. The compiler will only correctly translate characters in *unpacked* strings.

3 Support Unicode or UCS-4 and let the PAWN compiler convert scripts

encoded in UTF-8 to "wide" characters: when the source file for the PAWN compiler is in UTF-8 encoding, the compiler expands characters to Unicode/UCS-4 in *unpacked* strings.

4 Support UTF-8 encoding internally (in the host application) and write the source file in UTF-8 too: all strings should now be *packed* strings to avoid the compiler to convert them.

For most internationalization strategies, as you can see, the host application needs to support Unicode or UCS-4. As a side note, the PAWN compiler does *not* generate Unicode surrogate pairs. If characters outside the BMP are needed and the host application (or operating system) does not support the full UCS-4 encoding, the host application must split the 32-bit character `cell` provided by the PAWN compiler into a surrogate pair.

Packed & unpacked strings: 100

The PAWN compiler accepts a source file as an UTF-8 encoded text file —see page 169. When the source file is in UTF-8 encoding, "wide" characters in an *unpacked* string are stored as multi-byte Unicode/UCS-4 characters; wide characters in a *packed* string remain in UTF-8 encoding. To write source files in UTF-8 encoding, you need, of course, a (programmer's) editor that supports UTF-8. Codepage translation does not apply for files that are in UTF-8 encoding.

Escape sequence: 99

For an occasional Unicode character in a literal string, an alternative is that you use an escape sequence. As Unicode character tables are usually documented with hexadecimal glyph indices, the `\x`*hhh*`;` sequence is probably the more convenient specification of a random Unicode character. For example, the escape sequence "`\x2209`" stands for the "∉" character.

There is a lot more to internationalization than just basic support for extended character sets, such as formatting date & time fields, reading order (left-to-right or right-to-left) and locale-driven translation of system messages. The PAWN toolkit delegates these issues to the host application.

• Working with tags

Tag names: 67

The tag name system was invented to add a "usage checking" mechanism to PAWN. A tag denotes a "purpose" of a value or variable, and the PAWN compiler issues a diagnostic message when the tag of an expression does not match the required tag for the context of the expression.

Many modern computer languages offer variable *types*, where a type specifies the memory layout and the purpose of the variable. The programming language then checks the type equivalence; the PASCAL language is very strict at checking type equality, whereas the C programming language is more forgiving. The PAWN language does not have types: all variables have the size and the layout of a cell, although bit representations in the cell may depend on the purpose of the variable. In summary:

- ◇ a type specifies the *memory layout* and the range of variables and function results
- ◇ a tagname labels the *purpose* of variables, constants and function results

Tags in PAWN are mostly optional. A program that was "fortified" with tag names on the variable and constant declarations will function identically when all tag names are removed. One exception is formed by user-defined operators: the PAWN compiler uses the tags of the operands to choose between any user-defined operators and the standard operator.

User-defined operators: 86

The snippet below declares three variables and does three assignments, two of which give a "tag mismatch" diagnostic message:

Listing: **comparing apples to oranges**

```
new apple:elstar        /* variable "elstar" with tag "apple" */
new orange:valencia     /* variable "valencia" with tag "orange" */
new x                   /* untagged variable "x" */

elstar = valencia       /* tag mismatch */
elstar = x              /* tag mismatch */
x = valencia            /* ok */
```

The first assignment causes a "tag mismatch" diagnostic as it assigns an "orange" tagged variable to a variable with an "apple" tag. The second assignment puts the untagged value of `x` into a tagged variable, which causes again a diagnostic. When the untagged variable is on the left hand of the assignment operator, as in the third assignment, there is no warning or error message. As variable `x` is untagged, it can accept a value of any weak tag.

More tag name rules: 67

The same mechanism applies to passing variables or expressions to functions as function operands —see page 78 for an example. In short, when a function expects a particular tag name on an argument, you must pass an expression/variable with a matching tag to that function; but if the function expects an *un*tagged argument, you may pass in arguments with *any* weak tag.

On occasion, it is necessary to temporarily change the tag of an expression. For example, with the declarations of the previous code snippet, if you would

wish to compare apples with oranges (recent research indicates that comparing apples to oranges is not as absurd than popular belief holds), you could use:

```
if (apple:valencia < elstar)
    valencia = orange:elstar
```

The test expression of the `if` statement (between parentheses) compares the variable `valencia` to the variable `elstar`. To avoid a "tag mismatch" diagnostic, it puts a tag override `apple:` on `valencia` —after that, the expressions on the left and the right hands of the `>` operator have the same tag name: "`apple:`". The second line, the assignment of `elstar` to `valencia`, overrides the tag name of `elstar` or `orange:` before the assignment. In an assignment, you cannot override the tag name of the destination; i.e., the left hand of the `=` operator. It is an error to write "`apple:valencia = elstar`". In the assignment, `valencia` is an "lvalue" and you cannot override the tag name of an lvalue.

lvalue (definition of ~): 105

As shown earlier, when the left hand of an assignment holds an untagged variable, the expression on the right hand may have any weak tag name. When used as an lvalue, an untagged variable is compatible with all weak tag names. Or rather, a weak tag is silently dropped when it is assigned to an untagged variable or when it is passed to a function that expects an untagged argument. When a tag name indicates the bit pattern of a cell, silently dropping a weak tag can hide errors. For example, the snippet below has an error that is not immediately obvious:

Listing: **bad way of using tags**

```
#pragma rational float

new limit = -5.0
new value = -1.0

if (value < limit)
    printf("Value %f below limit %f\n", value, limit)
else
    printf("Value above limit\n")
```

Through the "`#pragma rational`", all rational numbers receive the "`float`" tag name and these numbers are encoded in the 4-byte IEEE 754 format. The snippet declares two variables, `limit` and `value`, both of which are *un*tagged (this is the error). Although the literal values `-5.0` and `-1.0` are implicitly tagged with `float:`, this weak tag is silently dropped when the values get assigned to the untagged symbols `limit` and `value`. Now, the `if` statement compares `value` to `limit` as integers, using the built-in

standard `<` operator (a user-defined operator would be more appropriate to compare two IEEE 754 encoded values). When run, this code snippet tells us that "`Value -1.000000 below limit -5.000000`" —which is incorrect, of course.

To avoid such subtle errors to go undetected, one should use *strong* tags. A strong tag is merely a tag name that starts with an upper case letter, such as `Float:` instead of `float:`. A strong tag is never automatically "dropped", but it may still be explicitly overridden. Below is a modified code snippet with the proposed adaptations:

Listing: **strong tags are safer**

```
#pragma rational Float

new Float:limit = -5.0
new Float:value = -1.0

if (value < limit)
    printf("Value %f below limit %f\n", _:value, _:limit)
else
    printf("Value above limit\n")
```

Forgetting the `Float:` tag name in the declaration of the variables `limit` or `value` immediately gives a "tag mismatch" diagnostic, because the literal values `-5.0` and `-1.0` now have a strong tag name.

`printf` is a general purpose function that can print strings and values in various formats. To be general purpose, `printf` accepts arguments with any weak tag name, be it `apple:`'s, `orange:`'s, or something else. The `printf` function does this by accepting untagged arguments —weak tags are dropped when an untagged argument is expected. Strong tags, however, are never dropped, and in the above snippet (which uses the original definition of `printf`), I needed to put an empty tag override, "`_:`", before the variables `value` and `limit` in the first `printf` call.

There is an alternative to untagging expressions with strong tag names in general purpose functions: adjust the definition of the function to accept both all weak tags and a selective set of strong tag names. The PAWN language supports multiple tag names for every function arguments. The original definition of `printf` (from the file CONSOLE.INC) is:

```
native printf(const format[], ...);
```

By adding both a `Float:` tag and an empty tag in front of the ellipsis ("`...`"), `printf` will accept arguments with the `Float:` tag name, arguments without a tag name and arguments that have a weak tag name. To specify plural tag names, enclose all tag names without their final colon between braces with a comma separating the tag names (see the example below). It is necessary to add the empty tag specification to the list of tag names, because `printf` would otherwise *only* accept arguments with a `Float:` tag name. Below is the new definition of the function `printf`:

```
native printf(const format[], {Float, _}: ...);
```

Plural tags allow you to write a single function that accepts cells with a precisely specified subset of tags (strong and/or weak). While a function argument may accept being passed *actual* arguments with diverse tags, a variable can only have a single tag —and a *formal* function argument is a local variable in the body of the function. In the presence of plural tags, the formal function argument takes on the tag that is listed first.

On occasion, you may want to check which tag an *actual* function argument had, when the argument accepts plural tags. Checking the tag of the formal argument (in the body of the function) is of no avail, because it will always have the first tag in the tag list in the declaration of the function argument. You can check the tag of the actual argument by adding an extra argument to the function, and set its default value to be the "`tagof`" of the argument in question. Similar to the `sizeof` operator, the `tagof` operator has a special meaning when it is applied in a default value of a function argument: the expression is evaluated at the point of the function *call*, instead of at the function definition. This means that the "default value" of the function argument is the actual tag of the parameter passed to the function.

Directives: 77

Inside the body of the function, you can compare the tag to known tags by, again, using the `tagof` operator.

• Concatenating lines

PAWN is a free format language, but the parser directives must be on a single line. Strings may not run over several lines either. When this is inconvenient, you can use a backslash character ("\") at the end of a line to "glue" that line with the next line.

Directives: 118

For example:

```
#define max_path        max_drivename + max_directorystring + \
                        max_filename + max_extension
```

You also use the concatenation character to cut long literal strings over multiple lines. Note that the "\" eats up all trailing white space that comes after it and leading white space on the next line. The example below prints "Hello world" with one space between the two words (because there is a space between "Hello" and the backslash):

```
print("Hello \
      world")
```

An alternative way to concatenate literal strings is to separate strings, that are each enclosed in pairs of double quotes, with an ellipsis. The next example is equivalent to the previous one:

```
print("Hello " ...
      "world")
```

• A program that generates its own source code

An odd, slightly academic, criterion to quantify the "expressiveness" of a programming language is size of the smallest program that, upon execution, regenerates its own source code. The rationale behind this criterion is that the shorter the self-generating program, the more flexible and expressive the language must be. Programs of this kind have been created for many programming languages —sometimes surprisingly small, as for languages that have a built-in reflective capabilities.

Self-generating programs are called "quines", in honour of the philosopher Willard Van Orman Quine who wrote self-creating phrases in natural language. The work of Van Orman Quine became well known through the books "Gödel, Escher, Bach" and "Metamagical Themas" by Douglas Hofstadter.

The PAWN quine is in the example below; it is modelled after the famous "C" quine (of which many variations exist). At 77 characters, it is amongst the smallest versions for the class of imperative programming languages, and the size can be reduced to 73 characters by removing four "space" characters that were left in for readability.

Listing: **quine.p**

```
new s[]="new s[]=%c%s%c; main() printf s,34,s,34"; main() printf s,34,s,34
```

APPENDIX A

Error and warning messages

When the compiler finds an error in a file, it outputs a message giving, in this order:
◇ the name of the file
◇ the line number were the compiler detected the error between parentheses, directly behind the filename
◇ the error class ("error", "fatal error" or "warning")
◇ an error number
◇ a descriptive error message

For example:

```
demo.p(3) : error 001: expected token: ";", but found "{"
```

Note: the line number given by the compiler may specify a position behind the actual error, since the compiler cannot always establish an error before having analyzed the complete expression.

After termination, the return code of the compiler is:
0 no errors —there may be warnings, though
1 errors found
2 *reserved*
3 aborted by user

These return codes may be checked within batch processors (such as the "`make`" utility).

• Error categories

Errors are separated into three classes:

Errors	Describe situations where the compiler is unable to generate appropriate code. Errors messages are numbered from 1 to 99.
Fatal errors	Fatal errors describe errors from which the compiler cannot recover. Parsing is aborted. Fatal error messages are numbered from 100 to 199.
Warnings	Warnings are displayed for unintended compiler assumptions and common mistakes. Warning messages are numbered from 200 to 299.

• **Errors**

001 **expected token:** *token*, **but found** *token*
A required token is omitted.

002 **only a single statement (or expression) can follow each "case"**
Every case in a switch statement can hold exactly one statement. To put multiple statements in a case, enclose these statements between braces (which creates a compound statement).

Pitfalls: 134
Compound statement: 113

003 **declaration of a local variable must appear in a compound block**
The declaration of a local variable must appear between braces ("`{...}`") at the active scope level.

When the parser flags this error, a variable declaration appears as *the only statement* of a function or *the only statement* below an `if`, `else`, `for`, `while` or `do` statement. Note that, since local variables are accessible only from (or below) the scope that their declaration appears in, having a variable declaration *as the only statement* at any scope is useless.

Compound statement: 113

004 **function** *name* **is not implemented**
There is no implementation for the designated function. The function may have been "forwardly" declared —or prototyped— but the full function definition including a statement, or statement block, is missing.

Forward declaration: 82

005 **function may not have arguments**
The function `main()` is the program entry point. It may not have arguments.

006 **must be assigned to an array**
String literals or arrays must be assigned to an array. This error message may also indicate a missing index (or indices) at the array on the right side of the "=" sign.

007 **operator cannot be redefined**
Only a select set of operators may be redefined, this operator is not one of them. See page 86 for details.

008 **must be a constant expression; assumed zero**
The size of arrays and the parameters of most directives must be constant values.

009 **invalid array size (negative, zero or out of bounds)**
The number of elements of an array must always be 1 or more. In addition, an array that big that it does exceeds the range of a cell is invalid too.

010 **illegal function or declaration**
The compiler expects a declaration of a global variable or of a function at the current location, but it cannot interpret it as such.

011 **invalid outside functions**
The instruction or statement is invalid at a global level. Local labels and (compound) statements are only valid if used within functions.

012 **invalid function call, not a valid address**
The symbol is not a function.

013 **no entry point (no public functions)**
The file does not contain a `main` function or any public function. The compiled file thereby does not have a starting point for the execution.

014 **invalid statement; not in switch**
The statements `case` and `default` are only valid inside a `switch` statement.

015 **"default" must be the last clause in switch statement**
PAWN requires the `default` clause to be the last clause in a `switch` statement.

016 **multiple defaults in "switch"**
Each `switch` statement may only have one `default` clause.

017 **undefined symbol** *symbol*
The symbol (variable, constant or function) is not declared.

Initialization: 64

018 **initialization data exceeds declared size**
An array with an explicit size is initialized, but the number of initiallers exceeds the number of elements specified. For example, in "`arr[3]={1,2,3,4};`" the array is specified to have three elements, but there are four initiallers.

019 **not a label:** *name*
A `goto` statement branches to a symbol that is not a label.

020 **invalid symbol name**
A symbol may start with a letter, an underscore or an "at" sign ("@") and may be followed by a series of letters, digits, underscore characters and "@" characters.

Symbol name syntax: 97

021 **symbol already defined:** *identifier*
The symbol was already defined at the current level.

022 **must be lvalue (non-constant)**
The symbol that is altered (incremented, decremented, assigned a value, etc.) must be a variable that can be modified (this kind of variable is called an lvalue). Functions, string literals, arrays and constants are no lvalues. Variables declared with the "`const`" attribute are no lvalues either.

023 **array assignment must be simple assignment**
When assigning one array to another, you cannot combine an arithmetic operation with the assignment (e.g., you cannot use the "+=" operator).

024 **"break" or "continue" is out of context**
The statements `break` and `continue` are only valid inside the context of a loop (a `do`, `for` or `while` statement). Unlike the languages C/C^{++} and Java, `break` does not jump out of a `switch` statement.

025 **function heading differs from prototype**
The number of arguments given at a previous declaration of the function does not match the number of arguments given at the current declaration.

026 **no matching "#if..."**
The directive `#else` or `#endif` was encountered, but no matching `#if` directive was found.

027 **invalid character constant**
One likely cause for this error is the occurrence of an unknown escape sequence, like "`\x`". Putting multiple characters between single quotes, as in `'abc'` also issues this error message. A third cause for this error is a situation where a character constant was expected, but none (or a non-character expression) were provided.

Escape sequence: 99

028 **invalid subscript (not an array or too many subscripts): *identifier***
The subscript operators "[" and "]" are only valid with arrays. The number of square bracket pairs may not exceed the number of dimensions of the array.

029 **invalid expression, assumed zero**
The compiler could not interpret the expression.

030 **compound statement not closed at the end of file**
An unexpected end of file occurred. One or more compound statements are still unfinished (i.e. the closing brace "}" has not been found).

031 **unknown directive**
The character "#" appears first at a line, but no valid directive was specified.

032 **array index out of bounds**
The array index is larger than the highest valid entry of the array.

033 **array must be indexed (variable *name*)**
An array as a whole cannot be used in a expression; you must indicate an element of the array between square brackets.

034 **argument does not have a default value (argument *index*)**
You can only use the argument placeholder when the function definition specifies a default value for the argument.

035 **argument type mismatch (argument *index*)**
The argument that you pass is different from the argument that the function expects, and the compiler cannot convert the passed-in argument to the required type. For example, you cannot pass the literal value "1" as an argument when the function expects an array or a reference.

036 **empty statement**
The line contains a semicolon that is not preceded by an expression. PAWN does not support a semicolon as an empty statement, use an empty compound block instead.

Empty compound block: 113

037 **invalid string (possibly non-terminated string)**
A string was not well-formed; for example, the final quote that ends a string is missing, or the filename for the `#include` directive was not enclosed in double quotes or angle brackets.

038 **extra characters on line**
There were trailing characters on a line that contained a directive (a directive starts with a `#` symbol, see page 118).

039 **constant symbol has no size**
A variable has a size (measured in a number of cells), a constant has no size. That is, you cannot use a (symbolic) constant with the `sizeof` operator, for example.

040 **duplicate "case" label (value** *value***)**
A preceding "case label" in the list of the `switch` statement evaluates to the same value.

041 **invalid ellipsis, array size is not known**
You used a syntax like "`arr[] = { 1, ... };`", which is invalid, because the compiler cannot deduce the size of the array from the declaration.

042 **invalid combination of class specifiers**
A function or variable is denoted as both "public" and "native", which is unsupported. Other combinations may also be unsupported; for example, a function cannot be both "public" and "stock" (a *variable* may be declared both "public" and "stock").

043 **character constant exceeds range for packed string**
Usually an attempt to store a Unicode character in a packed string where a packed character is 8-bits.

044 **mixing named and positional parameters**
You must either use named parameters or positional parameters for all parameters of the function.

045 **too many function arguments**
The maximum number of function arguments is currently limited to 64.

046 **unknown array size (variable** *name***)**
For array assignment, the size of both arrays must be explicitly defined, also if they are passed as function arguments.

047 **array sizes do not match, or destination array is too small**
For array assignment, the arrays on the left and the right side of the assignment operator must have the same number of dimensions. In addition:

- ◇ for multi-dimensional arrays, both arrays must have the same size;
- ◇ for single arrays with a single dimension, the array on the left side of the assignment operator must have a size that is equal or bigger than the one on the right side.

When passing arrays to a function argument, these rules also hold for the array that is passed to the function (in the function call) versus the array declared in the function definition.

When a function returns an array, all `return` statements must specify an array with the same size and dimensions.

048 **array dimensions do not match**
For an array assignment, the dimensions of the arrays on both sides of the "=" sign must match; when passing arrays to a function argument, the arrays passed to the function (in the function call) must match with the definition of the function arguments.

When a function returns an array, all `return` statements must specify an array with the same size and dimensions.

Single line comment: 97

049 **invalid line continuation**
A line continuation character (a backslash at the end of a line) is at an invalid position, for example at the end of a file or in a single line comment.

050 **invalid range**
A numeric range with the syntax "*n1* `..` *n2*", where *n1* and *n2* are numeric constants, is invalid. Either one of the values in not a valid number, or *n1* is not smaller than *n2*.

051 **invalid subscript, use "[ ]" operators on major dimensions**
You can use the "array character index" operator (braces: "`{ }`" only for the last dimension. For other dimensions, you must use the cell index operator (square brackets: "`[ ]`").

052 **multi-dimensional arrays must be fully initialized**
If an array with more than one dimension is initialized at its declaration, then there must be equally many literal vectors/sub-arrays at the right of the equal sign ("`=`") as specified for the major dimension(s) of the array.

053 **exceeding maximum number of dimensions**
The current implementation of the PAWN compiler only supports arrays with one or two dimensions.

054 **unmatched closing brace**
A closing brace ("`}`") was found without matching opening brace ("`{`").

055 **start of function body without function header**
An opening brace ("`{`") was found outside the scope of a function. This may be caused by a semicolon at the end of a preceding function header.

056 **local variables and function arguments cannot be public**
A local variable or a function argument starts with the character "@", which is invalid.

057 **Unfinished expression before compiler directive**
Compiler directives may only occur *between* statements, not *inside* a statement. This error typically occurs when an expression statement is split over multiple lines and a compiler directive appears between the start and the end of the expression. This is not supported.

058 **duplicate argument; same argument is passed twice**
In the function call, the same argument appears twice, possibly through a mixture of named and positional parameters.

Named versus positional parameters: 74

059 **function argument may not have a default value (variable *name*)**
All arguments of **public functions** must be passed explicitly. Public functions are typically called from the host application, who has no knowledge of the default parameter values. Arguments of **user defined operators** are implied from the expression and cannot be inferred from the default value of an argument.

060 **multiple "#else" directives between "#if ... #endif**
Two or more `#else` directives appear in the body between the matching `#if` and `#endif`.

061 **"#elseif" directive follows an "#else" directive**
All `#elseif` directives must appear *before* the `#else` directive. This error may also indicate that an `#endif` directive for a higher level is missing.

062 **number of operands does not fit the operator**
When redefining an operator, the number of operands that the operator has (1 for unary operators and 2 for binary operators) must be equal to the number of arguments of the operator function.

063 **operator requires that the function result has a "bool" tag**
Logical and relational operators are defined as having a result that is either `true` (1) or `false` (0) and having a "bool" tag. A user defined operator should adhere to this definition.

064 **cannot change predefined operators**
One cannot define operators to work on untagged values, for example, because PAWN already defines this operation.

065 **function argument may only have a single tag (argument** *number*)
In a user defined operator, a function argument may not have multiple tags.

066 **function argument may not be a reference argument or an array (argument** *number*)
In a user defined operator, all arguments must be cells (non-arrays) that are passed "by value".

067 **variable cannot be both a reference and an array (variable** *name*)
A function argument may be denoted as a "reference" or as an array, but not as both.

068 **invalid rational number precision in #pragma**
The precision was negative or too high. For floating point rational numbers, the precision specification should be omitted.

069 **rational number format already defined**
This `#pragma` conflicts with an earlier `#pragma` that specified a different format.

#pragma rational: 123

070 **rational number support was not enabled**
A rational literal number was encountered, but the format for rational numbers was not specified.

071 **user-defined operator must be declared before use (function** *name***)**
Like a variable, a user-defined operator must be declared before its first use. This message indicates that prior to the declaration of the user-defined operator, an instance where the operator was used on operands with the same tags occurred. This may either indicate that the program tries to make mixed use of the default operator and a user-defined operator (which is unsupported), or that the user-defined operator must be "forwardly declared".

Forward declaration: 82

072 **"sizeof" operator is invalid on "function" symbols**
You used something like "`sizeof MyCounter`" where the symbol "`MyCounter`" is not a variable, but a function. You cannot request the size of a function.

073 **function argument must be an array (argument** *name***)**
The function argument is a constant or a simple variable, but the function requires that you pass an array.

074 **#define pattern must start with an alphabetic character**
Any pattern for the `#define` directive must start with a letter, an underscore ("`_`") or an "`@`"-character. The pattern is the first word that follows the `#define` keyword.

075 **input line too long (after substitutions)**
Either the source file contains a very long line, or text substitutions make a line that was initially of acceptable length grow beyond its bounds. This may be caused by a text substitution that causes recursive substitution (the pattern matching a portion of the replacement text, so that this part of the replacement text is also matched and replaced, and so forth).

076 **syntax error in the expression, or invalid function call**
The expression statement was not recognized as a valid statement (so it is a "syntax error"). From the part of the string that was parsed, it looks as if the source line contains a function call in a "procedure call" syntax (omitting the parentheses), but the function result is used —assigned to a variable, passed as a parameter, used in an expression...

077 **malformed UTF-8 encoding, or corrupted file:** *filename*
The file starts with an UTF-8 signature, but it contains encodings that are invalid UTF-8. If the source file was created by an editor or converter that supports UTF-8, the UTF-8 support is non-conforming.

078 **function uses both "return" and "return <value>"**
The function returns both *with* and *without* a return value. The function should be consistent in always returning with a function result, or in never returning a function result.

079 **inconsistent return types (array & non-array)**
The function returns both values and arrays, which is not allowed. If a function returns an array, all `return` statements must specify an array (of the same size and dimensions).

080 **unknown symbol, or not a constant symbol (symbol** *name***)**
Where a constant value was expected, an unknown symbol or a non-constant symbol (variable) was found.

081 **cannot take a tag as a default value for an indexed array parameter (symbol** *name***)**
The `tagof` operator was used on an array parameter where the array also had an index. This is unsupported.

082 **user-defined operators and native functions may not have states**
Only standard and public functions may have states.

083 **a function or variable may only belong to a single automaton (symbol** *name***)**
There are multiple automatons in the state declaration for the indicated function or variable, which is not supported. In the case of a function: *all* instances of the function must belong to the same automaton. In the case of a variable: it is allowed to have several variables with the same name belonging to different automatons, but only in separate declarations —these are distinct variables.

State specifiers: 83

084 **state conflict: one of the states is already assigned to another implementation (symbol** *name***)**
The specified state appears in the state specifier of two implementations of the same function.

085 **no states are defined for symbol** *name*
When this error occurs on a function, this function has a fall-back implementation, but no other states. If the error refers to a variable, this variable does not have a list of states between the < and > characters. Use a state-less function or variable instead.

Fall-back: 83

086 **unknown automaton** *name*
The "`state`" statement refers to an unknown automaton.

087 **unknown state** *name* **for automaton** *name*
The "`state`" statement refers to an unknown state (for the specified automaton).

088 **public variables and local variables may not have states (symbol** *name***)**
Only standard (global) variables may have a list of states (and an automaton) at the end of a declaration.

089 **state variables may not be initialized (symbol** *name***)**
Variables with a state list may not have initializers. State variables should always be initialized through an assignment (instead of at their declaration), because their initial value is indeterminate.

090 **public functions may not return arrays (symbol** *name***)**
A public function may not return an array. Returning arrays is allowed only for normal functions.

091 **ambiguous constant; tag override is required (symbol** *name***)**
The constant exists enumerations, with different tags. The expected tag is different from any of these enumerations, and therefore the parser cannot choose the correct constant automatically. You need to use a tag override to indicate the correct constant.

enum statement: 102

• **Fatal Errors**

100 **cannot read from file:** *filename*
The compiler cannot find the specified file or does not have access to it.

101 **cannot write to file:** *filename*
The compiler cannot write to the specified output file, probably caused by insufficient disk space or restricted access rights (the file could be read-only, for example).

102 **table overflow:** *table name*
An internal table in the PAWN parser is too small to hold the required data. Some tables are dynamically growable, which means that there was insufficient memory to resize the table. The "table name" is one of the following:

"staging buffer": the staging buffer holds the code generated for an expression before it is passed to the peephole optimizer. The staging buffer grows dynamically, so an overflow of the staging buffer basically is an "out of memory" error.

"loop table": the loop table is a stack used with nested `do`, `for`, and `while` statements. The table allows nesting of these statements up to 24 levels.

"literal table": this table keeps the literal constants (numbers, strings) that are used in expressions and as initiallers for arrays. The literal table grows dynamically, so an overflow of the literal table basically is an "out of memory" error.

"compiler stack": the compiler uses a stack to store temporary information it needs while parsing. An overflow of this stack is probably caused by deeply nested (or recursive) file inclusion. The compiler stack grows dynamically, so an overflow of the compiler stack basically is an "out of memory" error.

"option table": in case that there are more options on the command line or in the response file than the compiler can cope with.

103 **insufficient memory**
General "out of memory" error.

104 **invalid assembler instruction** *symbol*
An invalid opcode in an `#emit` directive.

105 **numeric overflow, exceeding capacity**
A numeric constant, notably a dimension of an array, is too large for the compiler to handle. For example, when compiled as a 16-bit application, the compiler cannot handle arrays with more than 32767 elements.

106 **compiled script exceeds the maximum memory size (*number* bytes)**

The memory size for the abstract machine that is needed to run the script exceeds the value set with `#pragma amxlimit`. This means that the script is too large to be supported by the host.

See also #pragma amxlimit on page 120

You might try reducing the script's memory requirements by:

- ◇ setting a smaller stack/heap area —see `#pragma dynamic` at page 122;
- ◇ using packed strings instead of unpacked strings —see pages 100 and 137;
- ◇ putting repeated code in separate functions;
- ◇ putting repeated data (strings) in global variables;
- ◇ trying to find more compact algorithms to perform the same task.

107 **too many error/warning messages on one line**

A single line that causes several error/warning messages is often an indication that the PAWN parser is unable to "recover" from an earlier error. In this situation, the parser is unlikely to make any sense of the source code that follows —producing only (more) inappropriate error messages. Therefore, compilation is halted.

108 **codepage mapping file not found**

The file for the codepage translation that was specified with the `-c` compiler option or the `#pragma codepage` directive could not be loaded.

#pragma codepage: 121

109 **invalid path:** *path name*

A path, for example for include files or codepage files, is invalid. Check the compiler options and, if used, the configuration file.

Configuration file: 174

110 **assertion failed:** *expression*

Compile-time assertion failed.

#assert directive: 118

111 **user error:** *message*

The parser fell on an `#error` directive.

#error directive: 118

• **Warnings**

200 **symbol is truncated to** *number* **characters**
The symbol is longer than the maximum symbol length. The maximum length of a symbol depends on whether the symbol is native, public or neither. Truncation may cause different symbol names to become equal, which may cause error 021 or warning 219.

201 **redefinition of constant/macro (symbol** *name***)**
The symbol was previously defined to a different value, or the text substitution macro that starts with the prefix *name* was redefined with a different substitution text.

202 **number of arguments does not match definition**
At a function call, the number of arguments passed to the function (actual arguments) differs from the number of formal arguments declared in the function heading. To declare functions with variable argument lists, use an ellipsis (`...`) behind the last known argument in the function heading; for example: `print(formatstring,...);` (see page 80).

203 **symbol is never used:** *identifier*
A symbol is defined but never used. Public functions are excluded from the symbol usage check (since these may be called from the outside).

204 **symbol is assigned a value that is never used:** *identifier*
A value is assigned to a symbol, but the contents of the symbol are never accessed.

205 **redundant code: constant expression is zero**
Where a conditional expression was expected, a constant expression with the value zero was found, e.g. "`while (0)`" or "`if (0)`". The the conditional code below the test is *never* executed, and it is therefore redundant.

206 **redundant test: constant expression is non-zero**
Where a conditional expression was expected, a constant expression with a non-zero value was found, e.g. `if (1)`. The test is redundant, because the conditional code is *always* executed.

To create an endless loop, use `for ( ;; )` instead of `while (1)`.

207 **unknown "#pragma"**
The compiler ignores the pragma. The `#pragma` directives may change between compilers of different vendors and between different versions of a compiler of the same version.

208 **function with tag result used before definition, forcing reparse**
When a function is "used" (invoked) before being declared, and that function returns a value with a tag name, the parser must make an extra pass over the source code, because the presence of the tag name may change the interpretation of operators (in the presence of user-defined operators). You can speed up the parsing/compilation process by declaring the relevant functions before using them.

User-defined operators: 86
Forward declaration: 82

209 **function should return a value**
The function does not have a `return` statement, or it does not have an expression behind the `return` statement, but the function's result is used in a expression.

210 **possible use of symbol before initialization:** *identifier*
A local (uninitialized) variable appears to be read before a value is assigned to it. The compiler cannot determine the actual order of reading from and storing into variables and bases its assumption of the execution order on the physical appearance order of statements an expressions in the source file.

211 **possibly unintended assignment**
Where a conditional expression was expected, the assignment operator (`=`) was found instead of the equality operator (`==`). As this is a frequent mistake, the compiler issues a warning. To avoid this message, put parentheses around the expression, e.g. `if ( (a=2) )`.

212 **possibly unintended bitwise operation**
Where a conditional expression was expected, a bitwise operator (`&` or `|`) was found instead of a Boolean operator (`&&` or `||`). In situations where a bitwise operation seems unlikely, the compiler issues this warning. To avoid this message, put parentheses around the expression.

Tags are discussed on page 67

213 **tag mismatch**
A tag mismatch occurs when:
- ◇ assigning to a tagged variable a value that is untagged or that has a different tag
- ◇ the expressions on either side of a binary operator have different tags
- ◇ in a function call, passing an argument that is untagged or that has a different tag than what the function argument was defined with
- ◇ indexing an array which requires a tagged index with no tag or a wrong tag name

214 **possibly a "const" array argument was intended:** *identifier*
Arrays are always passed by reference. If a function does not modify the array argument, however, the compiler can sometimes generate more compact and quicker code if the array argument is specifically marked as "`const`".

215 **expression has no effect**
The result of the expression is apparently not stored in a variable or used in a test. The expression or expression statement is therefore redundant.

216 **nested comment**
PAWN does not support nested comments.

217 **loose indentation**
Statements at the same logical level do not start in the same column; that is, the indents of the statements are different. Although PAWN is a free format language, loose indentation frequently hides a logical error in the control flow.
The compiler can also incorrectly assume loose indentation if the TAB size with which you indented the source code differs from the assumed size. This may happen if the source files use a mixture of TAB and space characters to indent lines. Sometimes it is then needed to tell the PAWN parser what TAB size to use, see `#pragma tabsize` on page 123 or the compiler option `-t` on page 170.

218 **old style prototypes used with optional semicolon**
When using "optional semicolons", it is preferred to explicitly declare forward functions with the `forward` keyword than using terminating semicolon.

219 **local variable** *identifier* **shadows a symbol at a preceding level**
A local variable has the same name as a global variable, a function, a function argument, or a local variable at a lower precedence level. This is called "shadowing", as the new local variable makes the previously defined function or variable inaccessible.

Note: if there are also error messages further on in the script about missing variables (with these same names) or brace level problems, it could well be that the shadowing warnings are due to these syntactical and semantical errors. Fix the errors first before looking at the shadowing warnings.

220 **expression with tag override must appear between parentheses**
In a `case` statement and in expressions in the conditional operator (" `? :` "), any expression that has a tag override should be enclosed between parentheses, to avoid the colon to be misinterpreted as a separator of the `case` statement or as part of the conditional operator.

221 **label name** *identifier* **shadows tag name**
A code label (for the `goto` instruction) has the same name as a previously defined tag. This may indicate a faultily applied tag override; a typical case is an attempt to apply a tag override on the variable on the left of the `=` operator in an assignment statement.

222 **number of digits exceeds rational number precision**
A literal rational number has more decimals in its fractional part than the precision of a rational number supports. The remaining decimals are ignored.

223 **redundant "sizeof": argument size is always 1 (symbol** *name***)**
A function argument has a as its default value the size of another argument of the same function. The "sizeof" default value is only useful when the size of the referred argument is unspecified in the declaration of the function; i.e., if the referred argument is an array.

#if . . . #else
. . . #endif: 118

224 **indeterminate array size in "sizeof" expression (symbol *name*)**
The operand of the `sizeof` operator is an array with an unspecified size. That is, the size of the variable cannot be determined at compile time. If used in an "`if`" instruction, consider a conditionally compiled section, replacing `if` by `#if`.

225 **unreachable code**
The indicated code will never run, because an instruction before (above) it causes a jump out of the function, out of a loop or elsewhere. Look for `return`, `break`, `continue` and `goto` instructions above the indicated line. Unreachable code can also be caused by an endless loop above the indicated line.

226 **a variable is assigned to itself (symbol *name*)**
There is a statement like "`x = x`" in the code. The parser checks for self assignments *after* performing any text and constant substitutions, so the left and right sides of an assignment may appear to be different at first sight. For example, if the symbol "`TWO`" is a constant with the value 2, then "`var[TWO] = var[2]`" is also a self-assignment.

Self-assignments are, of course, redundant, and they may hide an error (assignment to the wrong variable, error in declaring constants).

Note that the PAWN parser is limited to performing "static checks" only. In this case it means that it can only compare array assignments for self-assignment with constant array indices.

227 **more initiallers than enum fields**
An array whose size is declared with an `enum` symbol contains more values/fields as initiallers than the enumeration defines.

228 **length of initialler exceeds size of the enum field**
An array whose size is declared with an `enum` symbol, and the relevant enumeration field has a size. The initialler in the array contains more values than the size of the enumeration field allows.

229 **index tag mismatch (symbol *name*)**
When indexing an array, the expression used as the index has a different tag than what the one in the declaration of the array. See pages 28 and 67 for an explanation and examples.

230 **no implementation for state** *name* **in function** *name*, **no fall-back**
A function is lacking an implementation for the indicated state. The compiler cannot (statically) check whether the function will ever be called in that state, and therefore it issues this warning. When the function would be called for the state for which no implementation exists, the abstract machine aborts with a run time error.

See page 83 on how to specify a fall-back function, and page 43 for a description and an example.

231 **state specification on forward declaration is ignored**
A state specification is redundant on forward declarations. The function signature must be equal for all states. Only the implementations of the function are state-specific.

State specifiers: 83

232 **compaction buffer overflow**
Compact encoding may in some particular cases result in files that would actually be bigger than the non-compact encoding. The abstract machine cannot handle this, as it unpacks the P-code "in place". When the compiler detects this situation, it re-builds the file with compact encoding switched off. To avoid this warning, force building the file with plain ("non-compact") encoding —see page 121.

233 **state variable** *name* **shadows a global variable**
The state variable has the same name as a global variable (without state specifiers). This means that the global variable is inaccessible for a function with one of the same states as those of the variable.

234 **function is deprecated (symbol** *name*)
The script uses a function which as marked as "deprecated". The host application can mark (native) functions as deprecated when better alternatives for the function are available or if the function may not be supported in future versions of the host application.

235 **public function lacks forward declaration (symbol** *name*)
The script defines a public function, but no forward declaration of this function is present. Possibly the function name was written incorrectly. The requirement for forward declarations of public functions guards against a common error.

236 **unknown parameter in substitution (incorrect #define pattern)**
A #define pattern contains a parameter in the replacement (e.g. "%1", but one in the match pattern. See page 93 for the preprocessor syntax.

237 **recursive function** *name*
The specified function calls itself recursively. Although this is valid in PAWN, a self-call is often an error. Note that this warning is only generated when the PAWN parser/compiler is set to "verbose" mode.

238 **mixing string formats in concatenation**
In concatenating literals strings, strings with different formats (such as packed versus unpacked, and "plain" versus standard strings) were combined. This is usually an error. The parser uses the format of the first (left-most) string in the concatenation for the result.

APPENDIX B

The compiler

Many applications that embed the PAWN scripting language use the stand-alone compiler that comes with the PAWN toolkit. The PAWN compiler is a command-line utility, meaning that you must run it from a "console window", a terminal/shell, or a "DOS box" (depending on how your operating system calls it).

• Usage

Assuming that the command-line PAWN compiler is called "`pawncc`" (Unix/Linux) or "`pawncc.exe`" (DOS/Windows), the command line syntax is:

```
pawncc <filename> [more filenames...]  [options]
```

The input file name is any legal filename. If no extension is given, "`.pawn`" or "`.p`" is assumed. The compiler creates an output file with, by default, the same name as the input file and the extension "`.amx`".

After switching to the directory with the sample programs, the command:

```
pawncc hello
```

should compile the very first "hello world" example (page 3). *Should*, because the command implies that:

- ◇ the operating system can locate the "`pawncc`" program —you may need to add it to the search path;
- ◇ the PAWN compiler is able to determine its own location in the file system so that it can locate the include files —a few operating systems do not support this and require that you use the `-i` option (see below).

• Input file

The input file for the PAWN compiler, the "source code" file for the script/program, must be a plain text file. All reserved words and all symbol names (names for variables, functions, symbolic constants, tags, ...) must use the ASCII character set. Literal strings, i.e text between quotes, may be in extended ASCII, such as one of the sets standardized in the ISO 8859 norm —ISO 8859-1 is the well known "Latin 1" set.

Packed/unpacked strings: 100
Character constants: 99

The PAWN compiler also supports UTF-8 encoded text files, which are practical in an environment based on Unicode or UCS-4. The PAWN compiler

only recognizes UTF-8 encoded characters inside *unpacked* strings and character constants. The compiler interprets the syntax rules for UTF-8 files strictly; non-conforming UTF-8 files are not recognized. The input file may have, but does not require, a "Byte Order Mark" signature; the compiler recognizes the UTF-8 format based on the file's content.

• Options

Options start with a dash ("`-`") or, on Microsoft Windows and DOS, with a forward slash ("`/`"). In other words, all platforms accept an option written as "`-a`" (see below for the purpose of this option) and the DOS/Windows platforms accept "`/a`" as an alternative way to write "`-a`".

All options should be separated by at least one space.

Many options accept a value —which is sometimes mandatory. A value may be separated from the option letter by a colon or an equal sign (a ":" and a "=" respectively), or the value may be glued to the option letter. Three equivalent options to set the debug level to two are thus:

◇ `-d2`
◇ `-d:2`
◇ `-d=2`

The options are:

`-a` Assembler: generate a text file with the pseudo-assembler code for the PAWN abstract machine, instead of binary code.

`-C+/-` Compact encoding of the binary file, which reduces the size a the output file typically to less than half the original size. Use `-C+` to enable it and `-C-` to revert to "plain" encoding. The option `-C` (without + or − suffix) toggles the current setting. Compact encoding is forced off when overlay code is generated.

`-c`*name* Codepage: set the codepage for translating the source file from extended ASCII to Unicode/UCS-4. The default is *no translation*. The *name* parameter can specify a full path to a "mapping file" or just the identifier of the codepage —in the latter case, the compiler prefixes the identifier with the letters "`cp`", appends the extension "`.txt`" and loads the mapping file from a system directory.

`-D`*path* Directory: the "active" directory, where the compiler should search for its input files and store its output files.

This option is not supported on every platform. To verify whether the PAWN compiler supports this option, run the compiler without any option or filename on the command line. The compiler will then list its usage syntax and all available options in alphabetical order. If the `-D` switch is absent, the option is not available.

`-d`*level* Debug level: 0 = none, 1 = bounds checking and assertions only, 2 = full symbolic information, 3 = full symbolic information and optimizations disabled (same as the combination `-d2` and `-O0`).

When the debug level is 2 or 3, the PAWN compiler also prints the estimated number of stack/heap space required for the program.

`-e`*filename* Error file: set the name of the file into which the compiler must write any warning and error messages; when set, there is no output to the screen.

`-H`*value* "`HWND`" (Microsoft Windows version only): the compiler can optionally post a message to the specified window handle upon completion of the P-code generation. Host applications that invoke the PAWN compiler can wait for the arrival of this message or signal the user of the completion of the compile.

The message number that is sent to the window is created with the Microsoft Windows SDK function `RegisterWindowMessage` using the name "PawnNotify". The `wParam` of the message holds the compiler return code: 0 = success, 1 = warnings, 2 = errors (plus possibly warnings), 3 = compilation aborted by the user.

`-i`*pathname* Include path: set the path where the compiler can find the include files. This option may appear multiple times at the command line, to allow you to set several include paths.

`-l` Listing: perform only the file reading and preprocessing steps; for example, to verify the effects of macro expansion and the conditionally compiled/skipped sections.

`-O`*level* Optimization level: 0 = no optimizations; 1 = JIT compatible optimizations only (*JIT* = "Just In Time" compiler, a high-performance abstract machine); 2 = full optimizations.

`-o`*filename* Output file: set the name and path of the binary output file.

`-p`*filename* Prefix file: the name of the "prefix file", this is a file that is parsed before the input file (as a kind of implicit "include file"). If used, this option overrides the default include file "DEFAULT.INC". The `-p` option on its own (without a filename) disables the processing of any implicit include file.

`-r`*filename* Report: enable the creation of the report and optionally set the filename to which the extracted documentation and a cross-reference report will be written.

The report is in "XML" format. The *filename* parameter is optional; if not specified, the report file has the same name as the output file with the extension "`.XML`".

`-S`*value* Stack size: the size of the stack and the heap in cells.

#pragma dynamic: 122

`-s`*value* Skip count: the number of lines to skip in the input file before starting to compile; for example, to skip a "header" in the source file which is not in a valid PAWN syntax.

`-t`*value* TAB size: the number of space characters to use for a TAB character. Without this option, the PAWN parser will autodetect the TAB.

`-V+/-/`*value* Generate the necessary tables and instructions for running the code from overlays. Using overlays reduces the memory requirements for a compiled script, because code sections can be swapped into and out off memory dynamically. Since overlay loading takes time, the resulting script will also run slower. Use `-V+` to enable overlays and `-V-` to create monolithic code —alternatively, use `-V` followed by a value to enable overlays and set the size of the overlay pool. The option `-V` without any suffix toggles the current setting.

`-v`*value* Verbose: display informational messages during the compilation. The value can be 0 (zero) for "quiet" compile, 1 (one) for the normal output and 2 for a code/data/stack usage report.

`-w`*value*`+/-` Warning control: the warning number following the "`-w`" is enabled or disabled, depending on whether a "+" or a "-" follows the number. When a "+" or "-" is absent, the warning status is toggled. For example, `-w225-` disables the warning for "unreachable code", `-w225+` enables it and `-w225` toggles between enabled/disabled.

Warnings: 162

Only warnings can be disabled (errors and fatal errors cannot be disabled). By default, all warnings are enabled.

`-X`*value* Limit for the abstract machine: the *maximum* memory requirements that a compiled script may have, in bytes. This value is is useful for (embedded) environments where the maximum size of a script is bound to a hard upper limit. If there is no setting for the amount of RAM for the data and stack, this refers to the total memory requirements; if the amount of RAM is explicitly set, this value only gives the amount of memory needed for the code and the static data.

See also #pragma amxlimit on page 120

`-XD`*value* RAM limit for the abstract machine: the *maximum* memory requirements for data and stack that a compiled script may have, in bytes. This value is is useful for (embedded) environments where the maximum data size of a script is bound to a hard upper limit. Especially in the case where the PAWN script runs from ROM, the sizes for the code and data sections need both to be set.

See also #pragma amxram on page 121

`-\` Control characters start with "\" (for the sake of similarity with C, C++ and Java).

`-^` Control characters start with "^" (for compatibility with earlier versions of PAWN).

`-;`*+/-* With `-;+` every statement is required to end with a semicolon; with `-;-`, semicolons are optional to end a statement if the statement is the last on the line. The option `-;` (without + or − suffix) toggles the current setting.

sym`=`*value* define constant "*sym*" with the given (numeric) *value*, the *value* is optional;

`@`*filename* read (more) options from the specified "response file".

- **Response file**

To support operating systems with a limited command line length (e.g., Microsoft DOS), the PAWN compiler supports "response files". A response file is a text file that contains the options that you would otherwise put at the command line. With the command:

```
pawncc @opts.txt prog.pawn
```

the PAWN compiler compiles the file "`prog.pawn`" using the options that are listed in the response file "`opts.txt`".

- **Configuration file**

On platforms that support it (currently Microsoft DOS, Microsoft Windows and Linux), the compiler reads the options in a "configuration file" on start-up. The configuration file must have the name "`pawn.cfg`" and it must reside in the same directory as the compiler executable program.

In a sense, the configuration file is an implicit response file. Options specified on the command line may overrule those in the configuration file.

APPENDIX C

Rationale

The first issue in the presentation of a new computer language should be: *why a new language at all?*

Indeed, I *did* look at several existing languages before I designed my own. Many little languages were aimed at scripting the command shell (TCL, Perl, Python). Other languages were not designed as extension languages, and put the burden to embedding solely on the host application.

As I initially attempted to use Java as an extension language (rather than build my own, as I have done now), the differences between PAWN and Java are illustrative for the almost reciprocal design goals of both languages. For example, Java promotes distributed computing where "packages" reside on diverse machines, PAWN is designed so that the compiled applets can be easily stored in a compound file together with other data. Java is furthermore designed to be architecture neutral and application independent, inversely PAWN is designed to be tightly coupled with an application; native functions are a taboo to some extent in Java (at least, it is considered "impure"), whereas native functions are "the reason to be" for PAWN. From the viewpoint of PAWN, the intended use of Java is upside down: native functions are seen as an auxiliary library that the application —in Java— uses; in PAWN, native functions are part of "the application" and the PAWN program itself is a set of auxiliary functions that the application uses.

A language for scripting applications and devices: PAWN is targeted as an *extension language*, meant to write application-specific macros or subprograms with. PAWN is not the appropriate language for implementing business applications or operating systems in. PAWN is designed to be easily integrated with, and embedded in, other systems/applications. It is also designed to run in resource-constrained environments, such as on small microcontrollers.

As an extension language, PAWN programs typically manipulate objects of the host application. In an animation system, PAWN scripts deal with sprites, events and time intervals; in a communication application, PAWN scripts handle packets and connections. I assume that the host application or the device makes (a subset of) its resources and functionality available via functions, handles, magic cookies... in a similar way that a contemporary operating system provides an interface to processes written in C/C^{++} —e.g., the Win32

API ("handles everywhere") or GNU/Linux' "`glibc`". To that end, PAWN has a simple and efficient interface to the "native" functions of the host application. A PAWN script manipulates data objects in the host application through function calls, but it *cannot* access the data of the host application directly.

The first and foremost criteria for the PAWN language were execution speed and reliability. Reliability in the sense that a PAWN program should not be able to crash the application or tool in which it is embedded —at least, not easily. Although this limits the capabilities of the language significantly, the advantages are twofold:

- ◇ the application vendor can rest assured that its application will not crash due to user additions or macros,
- ◇ the user is free to experiment with the language with no (or little) risk of damaging the application files.

Speed is essential: PAWN programs would probably run in an abstract machine, and abstract machines are notoriously slow. I had to make a language that has low overhead and a language for which a fast abstract machine can be written. Speed should also be reliable, in the sense that a PAWN script should not slow down over time or have an occasional performance hiccup. Consequently, PAWN excludes any required "background process", such as garbage collection, and the core of the abstract machine does not implicitly allocate any system or application resources while it runs. That is, PAWN does not allocate memory or open files, not without the help of a native function that the script calls *explicitly*.

As Dennis Ritchie said, by intent the C language confines itself to facilities that can be mapped relatively efficiently and directly to machine instructions. The same is true for PAWN, and this is also a partial explication why PAWN looks so much like C. Even though PAWN runs on an *abstract* machine, the goal is to keep that abstract machine small and quick. PAWN is used in tiny embedded systems with RAM sizes of 32 kiB or less, as well as in high-performance games that need every processor cycle for their graphics engine and game-play. In both environments, a heavy-weight scripting support is difficult to swallow.

A brief analysis showed that the instruction decoding logic for an abstract machine would quickly become the bottleneck in the performance of the abstract machine. To keep the decoding simple, each opcode should have the same size (excluding operands), and the opcode should fully specify the

instruction (including the addressing methods, size of the operands, etc.). That meant that for each operation on a variable, the abstract machine needed a separate opcode for every combination of variable type, storage class and access method (direct, or dereferenced). For even three types (`int`, `char` and `unsigned int`), two storage classes (global and local) and three access methods (direct, indirect or indexed), a total of 18 opcodes (3*2*3) are needed to simply fetch the value of a variable.

At the same time, to keep the abstract machine small and manageable, I set the goal at approximately 100 instructions.* With 18 opcodes to load a variable in a register, 18 more to store a register into a variable, another 18 to get the address of a variable, etc... I was quickly exceeding my self-imposed limit of a hundred opcodes.

The languages BOB and REXX inspired me to design a typeless language. This saved me a lot of opcodes. At the same time, the language could no longer be called a "subset of C". I was changing the language. Why, then, not go a foot further in changing the language? This is where a few more design guidelines came into play:

- ◇ give the programmer a general purpose tool, not a special purpose solution
- ◇ avoid error prone language constructs; promote error checking
- ◇ be pragmatic

A general purpose tool: PAWN is targeted as an extension language, without specifying exactly what it will extent. Typically, the application or the tool that uses PAWN for its extension language will provide many, optimized routines or commands to operate on its native objects, be it text, database records or animated sprites. The extension language exists to permit the user to do what the application developer forgot, or decided not to include. Rather than providing a comprehensive library of functions to sort data, match regular expressions, or draw cubic Bézier splines, PAWN should supply a (general purpose) means to use, extend and combine the specific ("native") functions that an application provides.

PAWN lacks a comprehensive standard library. By intent, PAWN also lacks features like pointers, dynamic memory allocation, direct access to the op-

* 136 Opcodes are defined at this writing, plus 20 "macro" opcodes. To exploit performance gains by forcing proper alignment of memory words (essential on ARM microprocessors), the current abstract machine uses 32-bit opcodes. There is no technical limit on the number of opcodes, but in the interest of a small footprint, the number of opcodes should be restricted.

erating system or to the hardware, that are needed to remain competitive in the field of general purpose application or system programming. You cannot build linked lists or dynamic tree data structures in PAWN, and neither can you access any memory beyond the boundaries of the abstract machine. That is not to say that a PAWN program can never use dynamic, sorted symbol tables, or change a parameter in the operating system; it *can* do that, but it needs to do so by calling a "native" function that an application provides to the abstract machine.

In other words, if an application chooses to implement the well known `peek` and `poke` functions (from BASIC) in the abstract machine, a PAWN program can access any byte in memory, insofar the operating system permits this. Likewise, an application can provide native functions that insert, delete or search symbols in a table and allows several operations on them. The proposed core functions `getproperty` and `setproperty` are an example of native functions that build a linked list in the background.

Promote error checking: As you may have noticed, one of the foremost design criteria of the C language, "trust the programmer", is absent from my list of design criteria. Users of script languages may not be experienced programmers; and even if they are, PAWN will probably not be their *primary* language. Most PAWN programmers will keep learning the language as they go, and will even after years not have become experts. Enough reason, hence, to replace error prone elements from the C language (pointers) with saver, albeit less general, constructs (references).† References are copied from C++. They are nothing else than pointers in disguise, but they are restricted in various, mostly useful, ways. Turn to a C++ book to find more justification for references.

I find it sad that many, even modern, programming languages have so little built-in, or easy to use, support for confirming that programs do as the programmer intended. I am not referring to theoretical correctness (which is too costly to achieve for anything bigger than toy programs), but practical, easy to use, verification mechanisms as a help to the programmer. PAWN provides both compile time and execution time assertions to use for preconditions, postconditions and invariants.

† You should see this remark in the context of my earlier assertion that many "Pawn" programmers will be novice programmers. In my (teaching) experience, novice programmers make many pointer errors, as opposed to experienced C/C++ programmers.

The typing mechanism that most programming languages use is also an automatic "catcher" of a whole class of bugs. By virtue of being a typeless language, PAWN lacked these error checking abilities. This was clearly a weakness, and I created the "tag" mechanism as an equivalent for verifying function parameter passing, array indexing and other operations.

The quality of the tools: the compiler and the abstract machine, also have a great impact on the robustness of code —whatever the language. Although this is only very loosely related to the design of the language, I set out to build the tools such that they promote error checking. The warning system of PAWN goes a step beyond simply reporting where the parser fails to interpret the data according to the language grammar. At several occasions, the compiler runs checks that are completely unrelated to generating code and that are implemented specifically to catch possible errors. Likewise, the "debugger hook" is designed right into the abstract machine, it is not an add-on implemented as an after-thought.

Be pragmatic: The object-oriented programming paradigm has not entirely lived up to its promise, in my opinion. On the one hand, OOP solves many tasks in an easier or cleaner way, due to the added abstraction layer. On the other hand, contemporary object-oriented languages leave you struggling with the language. The struggle should be with implementing the functionality for a specific task, not with the language used for the implementation. Object-oriented languages are attractive mainly because of the comprehensive class libraries that they come with —but leaning on a standard library goes against one of the design goal for PAWN. Object-oriented programming is not a solution for a non-expert programmer with little patience for artificial complexity. The criterion "be pragmatic" is a reminder to seek solutions, not elegance.

• Practical design criteria

The fact that PAWN looks so much like C cannot be a coincidence, and it isn't. PAWN started as a C dialect and stayed that way, because C has a proven track record. The changes from C were mostly born out of necessity after rubbing out the features of C that I did not want in a scripting language: no pointers and no "typing" system.

PAWN, being a typeless language, needed a different means to declare variables. In the course of modifying this, I also dropped the C requirement that

all variables should be declared at the top of a compound statement. PAWN is a little more like C++ in this respect.

C language functions can pass "output values" via pointer arguments. The standard function `scanf`, for example, stores the values or strings that it reads from the console into its arguments. You can design a function in C so that it optionally returns a value through a pointer argument; if the caller of the function does not care for the return value, it passes `NULL` as the pointer value. The standard function `strtol` is an example of a function that does this. This technique frequently saves you from declaring and passing dummy variables. PAWN replaces pointers with references, but references cannot be `NULL`. Thus, PAWN needed a different technique to "drop" the values that a function returns via references. Its solution is the use of an "argument placeholder" that is written as an underscore character ("_"); Prolog programmers will recognize it as a similar feature in that language. The argument placeholder reserves a temporary anonymous data object (a "cell" or an array of cells) that is automatically destroyed after the function call.

The temporary cell for the argument placeholder should still have a value, because the function may see a reference parameters as input/output. Therefore, a function must specify for each passed-by-reference argument what value it will have upon entry when the caller passes the placeholder instead of an actual argument. By extension, I also added default values for arguments that are "passed-by-value". The feature to optionally remove all arguments with default values from the right was copied from C++.

When speaking of BCPL and B, Dennis Ritchie said that C was invented in part to provide a plausible way of dealing with character strings when one begins with a word-oriented language. PAWN provides two options for working with strings, packed and unpacked strings. In an unpacked string, every character fits in a cell. The overhead for a typical 32-bit implementation is large: one character would take four bytes. Packed strings store up to four characters in one cell, at the cost of being significantly more difficult to handle if you could only access full cells. Modern BCPL implementations provide two array indexing methods: one to get a word from an array and one to get a character from an array. PAWN copies this concept, although the syntax differs from that of BCPL. The packed string feature also led to the new operator `char`.

Unicode applications often have to deal with two characters sets: 8-bit for

Support for Unicode string literals: 139

legacy file formats and standardized transfer formats (like many of the Internet protocols) and the 16-bit Unicode character set (or the 31-bit UCS-4 character set). Although the PAWN compiler has an option that makes characters 16-bit (so only two characters fit in a 32-bit cell), it is usually more convenient to store single-byte character strings in packed strings and multibyte strings in unpacked strings. This turns a weakness in PAWN —the need to distinguish packed strings from unpacked strings— into a strength: PAWN can make that distinction quite easily. And instead of needing two implementations for every function that deals with strings (an ASCII version and a Unicode version —look at the Win32 API, or even the standard C library), PAWN enables functions to handle *both* packed and unpacked strings with ease.

Notwithstanding the above mentioned changes, plus those in the chapter "Pitfalls: differences from C" (page 134), I have tried to keep PAWN close to C. A final point, which is unrelated to language design, but important nonetheless, is the license: PAWN is distributed under a liberal license allowing you to use and/or adapt the code with a minimum of restrictions —see appendix D.

APPENDIX D

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Index

◇ Names of persons (not products) are in *italics*.
◇ Function names, constants and compiler reserved words are in `typewriter font`.

!

`#`, 95
`#assert`, 118
`#define`, 93, 96, 118, 135
`#endinput`, 118
`#error`, 118
`#file`, 118
`#if`, 118
`#include`, 119
`#line`, 119
`#pragma`, 120
`#section`, 124
`#tryinclude`, 124
`#undef`, 95, 124
@-symbol, 62, 84
... considered harmful, 4

A

Actual parameter, 16, 68
Algebraic notation, 26
Alias, *See* External name
Alignment (variables), 120
Anno Domini, 11
APL, 27
Argument placeholder, 75
Array
  enumerated `~`, 19, 30, 65
Array assignment, 107, 134
Arrays, 65
  Progressive initiallers, 64
ASCII, 139, 141, 169, 170
Assertions, 9, 49, 104, 178
Automata theory, 41, 44, 45
Automaton, 37, 83, *see also* State
  anonymous, 116
  anonymous `~`, 41

B

Basic Multilingual Plane, 140
BCPL, 180
Big Endian, 100
Binary arithmetic, 25
Binary Coded Decimals, 104
Binary radix, 98, 134
Bisection, 79
Bit shifting increment, 25
`bitcount`, 25
Bitwise operators, 23
BOB, 177
Byte Order Mark, 170
Bytecode, *See* P-code

C

Cain, Ron, 1
Call by reference, 13, 17, 81
Call by value, 12, 17, 71, 89
Callee (functions), 73
Celsius, 14
Chained relational operators, 17, 108
`char`, 135
Character constants, 99
`clamp`, 125
`clreol`, 131
`clrscr`, 131

Codepage, 121, 139, 141, 142, 170
Coercion rules, 81
Comments, 97
  documentation ~, 51, 97
Commutative operators, 89
Compact encoding, 121, 170
Compiler options, 170
Compound literals, *See* Literal array
Conditional goto, 134
Configuration file, 174
Constants
  "const" variables, 63
  literals, 98
  predefined ~, 103
  symbolic ~, 102
Counting bits, 25
Cross-reference, 51, 172

D

Data declarations, 61–66
  arrays, 65
  default initialization, 64
  global ~, 61
  local ~, 61
  public ~, 62
  stock ~, 62
Date
  ~ arithmetic, 13
  functions, 132
Debug level, 104
Default arguments, 75
Default initialization, 64
`deleteproperty`, 130
Design by contract, 49
Diagnostic, 30, 68, 79, 142, *see also* Errors and Warnings
Digit group separator, 98, 99
Directives, 96, 118–124
DLL calls, 133
Documentation comments, 51, 97
Documentation tags, 172
Dr. Dobb's Journal, 1
Dynamic tree, 178

E

Eiffel, 49
Ellipsis operator, 64, 72, 80, 101, 147
`enum`, 19, 102
Enumerated array, 19, 30, 65
Eratosthenes, 7
Error, *see also* Diagnostic
Errors, 58, 148–161
Escape sequences, 99, 101
Euclides, 5
Event-driven programming model, 33, 35, 37
`existproperty`, 130
Extended ASCII, 139, 169
External name, 86, 90

F

Faculty, 71
`faculty`, 71
Fahrenheit, 14
Fall-back (state functions), 42, 83
Fibonacci, 8
`fibonacci`, 9
Fibonacci numbers, 9
File input/output, 132
Fixed point arithmetic, 79, 91, 132
Floating point arithmetic, 91, 99, 132, 134
Flow-driven programming model, 33, 35
Floyd, Robert, 77
Forbidden user-defined operators, 92
Foreign Function Interface, 133

Formal parameter, 68, 70
Forward declaration, 70, 82
FSM, *See* Automaton
`funcidx`, 125
Function library, 125
Functions, 70–86
  call by reference, 13, 17, 71
  call by value, 12, 17, 71, 89
  callee, 73
  caller, 73
  coercion rules, 81
  default arguments, 75
  forward declaration, 70, 82
  ~ index, 125
  latent ~, 115
  native ~, 9, 85
  public ~, 83
  standard library ~, 125
  state classifier, 83
  state entry ~, 41, 61
  state exit ~, 45
  static ~, 84
  stock ~, 84
  variable arguments, 80

G

Gödel, Escher, Bach, 147
`gcd`, 5
`getarg`, 126
`getchar`, 130
`getproperty`, 130
`getstring`, 130
`getvalue`, 130
Global variables, 61
Golden ratio, 10
`gotoxy`, 132
Greatest Common Divisor, 5
Gregorian calendar, 10

H

Hamblin, Charles, 27
Hanoi, the Towers of ~, 82
`heapspace`, 126
Hendrix, James, 1
Hexadecimal radix, 98, 134
Hofstadter, Douglas R., 147
Host application, 62, 63, 85, 114, 115, 125, 142, 175

I

Identifiers, 97
Implicit conversions, *See* coercion rules
Index tag, 30, 68
Indiction Cycle, 10
Infinite loop, 18
Infix notation, *See* Algebraic ~
Internationalization, 139
Internet, 180
`intersection`, 79
Intersection (sets), 22
ISO 8859, 100, 139, 169
ISO/IEC 10646-1, 140, 141
ISO/IEC 8824 (date format), 74
`ispacked`, 137

J

Jacquard Loom, 37
Java, 175
JIT, 172
Julian Day number, 10

K

Keywords, *See* reserved words

L

Latent function, 115
Latin-1, *See* ISO 8859
Leap year, 70
`leapyear`, 70
Leonardo of Pisa, 8
Library call, 133
Library functions, 85
License, 182
Linear congruential generator, 127
Linked lists, 178
Linux, 141, 175
LISP, 34
Literal array, 72
Literals, *See* Constants
Local variables, 61
Logo (programming language), 34
Lukasiewicz, Jan, 27
lvalue, 68, 105, 144

M

Macro, 93, 118
  ~ prefix, 95, 124
`max`, 126
Mealy automata, 44
Metonic Cycle, 10
Meyer, Bertrand, 49
Micro-controllers, 175
Microsoft Windows, 141
`min`, 127
MIRT, 44
Moore automata, 44
Multiplicative increment, 25

N

Named parameters, 74
Native functions, 9, 85
  external name, 86, 90
Newton-Raphson, 79
`numargs`, 127

O

Octal radix, 134
Operator precedence, 111
Operators, 105–111
  commutative ~, 89
  user-defined ~, 86, 143
Optional semicolons, 97
Options
  compiler ~, 170
Overlays, 122, 172

P

P-code, 93, 121, 167
Packed string, 100, 137, 180
Parameter
  actual ~, 16, 68
  formal ~, 68, 70
Parser, 4
Placeholder, *See* Argument ~
Plain encoding, 170
Plain strings, 101
Plural tag names, 146
Positional parameters, 74
`power`, 70
Precedence table, 111
Prefix file, 172
Preprocessor, 93–96
  ~ macro, 93, 118
Prime numbers, 7
`print`, 131
`printf`, 15, 131
Priority queue, 21
Procedure call syntax, 73
Process control, 133
Progressive initiallers, 64
Proleptic Gregorian calendar, 10
Pseudo-random numbers, 127
Public
  ~ functions, 83, 125
  ~ variables, 62

Q

Quincy, 58
Quine, 147

R

`random`, 127
Random sample, 77
Rational numbers, 14, 30, 99
Recursive functions, 81
Reference arguments, 13, 71, 81
Report, 172
Reserved words, 97
Response file, 174
Reverse Polish Notation, 27
REXX, 177
Ritchie, Dennis, 135, 176, 180
`rot13`, 16
ROT13 encryption, 16

S

Scaliger, Josephus, 10
Semicolons, optional, 97
Set operations, 22
`setarg`, 128
`setattr`, 132
`setproperty`, 130
Shadowing, 165
Shared libraries, 133
Shift-JIS, 140
`sieve`, 7
Single line comment, 97
sizeof operator, 110
  ~ in function argument, 77, 78
Small C, 1
Solar Cycle, 10
`sqroot`, 79
Square root, 79
Standard function library, 125
State, 37, 38
  ~ classifier, 40, 41, 45, 61, 83
  conditional ~, 40
  ~ diagram, 37, 47
  ~ entry function, 41, 61
  ~ exit function, 45
  fall-back ~, 42, 83
  ~ notation, 47
  ~ operator, 111
  unconditional ~, 43
  ~ variables, 44, 61
Statements, 113–117
Static
  ~ functions, 84
  ~ variables, 62
Stock
  ~ functions, 84
  ~ variables, 62
String
  ~ concatenation, 101
  packed ~, 100, 137, 180
  plain ~, 101
  unpacked ~, 100, 137, 180
String manipulation, 133
Stringize operator, 95
`strtok`, 17
Structure, 19, *see also* Enumerated array
`strupper`, 138
Surrogate pair, 140, 142
`swap`, 71
`swapchars`, 128
Symbolic constants, 102
Symbolic information, 171
Syntax rules, 97

T
Tag name, 15, 30, 67, 142
~ and enum, 102
array index, 30, 68
~ operator, 146
~ override, 68, 110, 144
plural tags, 146
predefined ~, 104
strong ~, 68, 145
~ syntax, 104
untag override, 145
weak ~, 68, 143
Tag names, 178
tagof operator, 111
Text substitution, 93, 118
The Towers of Hanoi, 82
Thousands separator, 98, 99
Time
functions, 132
`tolower`, 128
`toupper`, 129
Transition (state), 37
Turtle graphics, 34

U
UCS-4, 100, 140, 141, 169
Unicode, 100, 140, 141, 169, 170, 180
Union (sets), 22
UNIX, 141
Unpacked string, 100, 137, 180
Untag override, 145
User error, 118
User-defined operators, 86, 143
forbidden ~, 92
UTF-8, 141, 142, 158, 169

V
Van Orman Quine, Willard, 147
Variable arguments, 80
Variables, *See* Data declarations
state ~, 44
VETAG, 44
Virtual Machine, *See* Abstract ~

W
Warning, *see also* Diagnostic
Warnings, 162–168, 173
`weekday`, 74, 117
White space, 97
Whitesmith's style, 4
Wide character, 141
Word count, 17

X
XML, 51, 172
XSLT, 51

Y
Year zero, 11

Z
Zeller, 74