JAL 2.0 manual

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JAL 2.0 [3] is a high-level language for a number of Microchip ™ PIC microcontrollers [1].

It was created by KYLE YORK, who also wrote the *PICbsc* compiler [2]. STEF MIENTKI got in touch with KYLE YORK and ask him if he could look into rewriting *JAL* using the *PICbsc* engine, the prospect intrigued him. *JAL 2.0* not only shares the same *JAL [4]* syntax, but adds new features (like new types, arrays, etc.) to *JAL,* keeping the *PICbsc* internal compiler design as well. This manual covers all aspects of *JAL 2.0* without any reference to *JAL* trying to be useful for all, novices and users with *JAL* experience.

JAL was developed by WOUTER VAN OOIJEN[1]. He created *JAL* because he did not like any of the low-cost (or free) languages for these chips and implementing a high level language looked like a nice project.

For a quick impression of *JAL 2.0* here's a small example how *JAL 2.0* looks. Also, you could read either the summary[2] or the examples[3] section of this manual.

Example:

```
; microcontroller definition file
include c16F877_10

; set pin a0 direction as output
pin_a0_direction = output

; do forever the statements inside the loop
forever loop

  pin_a0 = ! pin_a0  ; complement value of a0
  delay_1s(1)        ; wait 1 second

end loop
```

[1] Wouter released JAL under GPL (http://jal.sourceforge.net) in January of 2003.
[2] See section 6 on page 91
[3] See section 4 on page 71

Contents

Revision history

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Written by: JAVIER MARTÍNEZ, DAVE LAGZDIN and VASILE SURDUCAN
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Modifications: corrected small *bugs,* added some suggestions and new compiler features.

1 Language definition

1.1 basics

1.1.1 Format

The *JAL 2.0* language is free-format (except for comments) and not case-sensitive. All characters with an ASCII value below the space (tab, carriage return, new line, form feed, etc.) are treated as spaces, except that the end of a line terminates a comment.

JAL 2.0 does not use statement separators. The only real separators are the comma's between the (formal or actual) arguments to a procedure or function "`( , )`", or in an array definition "`{ , }`".

Example:

```
-- if statement in preferred format
if a > b then
   a = b + 1
else
   a = b - 1
end if

-- but this has exactly the same effect
if a > b then a = b + 1 else a = b - 1 end if

-- comma's between actual arguments
f( a, b, c, d )
var byte msg[5] = "Hello"
```

1.1.2 Comments

A comment is started by the token "`--`" or "`;`" and continues until the end of the line.

Example:

```
-- the next line contains a comment
-- after the assignment
ticks = ticks + 1 ; one more tick

; the next line contains the same comment
; after the assignment
ticks = ticks + 1 -- one more tick
```

1.1.3 Includes

An include causes the content of the included file to be read. A subsequent include for the same file name will be ignored. This makes it possible for a library file to include all required lower libraries.

Included files are sought first in the current directory, and next in each location indicated by the compilers search path. All *JAL 2.0* files have the extension "`.jal`". Be care not to include this extension in the *include* statement.

Includes can be nested to any level.

Example:

```
include serial    -- include the serial.jal file
include i2c       -- include the i2c.jal file
```

1.1.4 Program

A *JAL 2.0* program is a sequence of statements. Declarations are also considered statements, so declarations can appear almost anywhere in a program.

Example:

```
-- my first program
var byte b       -- variable declaration
while b > 0 loop -- start of loop
   b = b + 1     -- variable assignment
end loop         -- end of loop
```

1.1.5 Scope

JAL 2.0 is a block-structured language, so each declaration is visible from its declaration to the end of the block in which the declaration appears (in practice this means to the first end at the current nesting level).

A declaration can hide a declaration of the same name from an enclosing block. A declaration can not hide a name which was already declared at the same nesting level.

Example:

```
var byte b
while b > 0 loop
   var bit b    -- Overrides the byte b defined
                -- outside the while block.

   b = false    -- The bit b, not the byte

   var byte b   -- Error, "b" already declared
                -- as a bit inside the while block.
end loop

var word b      -- Error, "b" already declared
                -- as a byte before while block.
```

1.1.6 Block

A block is a sequence of statements. Variables, constants, procedures, and functions defined in a block will not be visible outside of the block.

1.2 basic types

1.2.1 Built-in types

These are the types of range values that *JAL 2.0* supports.

BIT 1 bit unsigned boolean value (range is 0 or 1)[1].

BYTE 8 bit unsigned value (range is 0 .. 255).

SBYTE 8 bit signed value (range is -128 .. 127).

WORD 16 bit unsigned value (range is 0 .. 65,535).

SWORD 16 bit signed value (range is -32,768 .. 32,767).

DWORD 32 bit unsigned value (range is 0 .. 4,294,967,296).

SDWORD 32 bit signed value (range is -2,147,483,648 .. 2,147,483,647).

1.2.2 Extending types

Basic types can be extended using the token *[*cexpr]*[2] preceded by token *type*. Being *type* one of the following built-in types[3]: BIT, BYTE or SBYTE.

BYTE and *SBYTE*

For *BYTE* and *SBYTE*, this means the variable will be defined as an integer using *cexpr* bytes.

Example:

```
 WORD is simply shorthand for BYTE*2
DWORD is simply shorthand for BYTE*4
```

[1] *JAL 2.0* support aditional names for this range: *0 = FALSE = LOW = OFF* and *1=TRUE=HIGH=ON.*
[2] *cexpr* means a constant expression or a literal value.
[3] See section 1.2.1 on this page

BIT

If type is *BIT*, the definition changes. A *BIT* variable, as defined in *JAL*, is really of type boolean. When assigned any non-zero value, it takes on the value of 1.

Using the *[*cexpr*]*, the definition changes to be more like a C bit field: assignment is masked.

We can create a 'nibble-like' grouping of bits with range 0 to $(2^{cexpr} - 1)$, i.e.: with 2 bits we can count to 3 (0b11)

Example:

```
 VAR BIT*2 cc

-- when assigning to cc, the internal
-- compiler assignment is:
cc = (value & 0x03) -- mask 2 least significative bits
                    -- remember 0x03=0b00000011
```

1.3 Literals

Literals are numeric constants with a invariant value, the format is:

12 a decimal numeric constant

0x12 a hexadecimal numeric constant

0b01 a binary numeric constant

0q01 an octal numeric constant

"a" an ASCII char constant

"Hello" a *string* constant. Following *escape sequence* chars can be used inside a string:

Escape sequence char	Description
`\a`	Bell
`\b`	Backspace
`\f`	Form Feed
`\n`	Line Feed
`\r`	Carriage Return
`\t`	Horizontal TAB
`\v`	Vertical TAB
`\\`	\
`\?`	?
`\'`	’
`\"`	”
`\0`	Hexadecimal value: `0x00`
`\x##`	Hexadecimal value: `0x##`

Literals other than ASCII constants may also contain a number of underscores `"_"` which are ignored, but are useful for making them more readable.

Example:

```
 0b_0000_1111  -- a binary literal

-- a fuse definition (14 bit word)
0b_11_0000_1111_0000

1_234_567     -- a decimal literal
```

String constants can use C style initialization style, eg:

```
var byte string[] = "abc" "def" "ghi"
```

is the same as:

```
var byte string[] = "abcdefghi"
```

1.4 Constants

A constant declaration introduces a name which has a constant value throughout its scope. When the type is omitted the constant has a *SDWORD* type. A single constant declaration can introduce a number of constants of the same type.

```
CONST [type[*cexpr]] identifier [ '[' cexpr ']' ]

{ '=' cexpr | = '{' cexpr1[, cexpr2,...]'}' | = '"' cexpr '"'}

[ , identifier2...]
```

CONST denotes the beginning of a constant definition clause.

type[*cexpr] Defines the type of the constant. If none is given, the constant becomes universal type which is 32 bit signed (*SDWORD*).

'[' cexpr ']' Defines a constant table [4].
A constant table will not take any space unless it is indexed at least once with a non-constant subscript. On the PIC, constant tables consume *code* space, not *data* space, and are limited to 255 elements.

'=' cexpr For non-table constants this assigns the value to the constant.

'=' '{' cexpr1[, cexpr2 . . .] '}' For tables of constants this assigns the value to each element. There must be the same number of *cexprs* as there are elements defined.

"" cexpr "" A *string* constant can be assigned to a constant table:
`const byte x[] = "hello".`

Example:

```
 const byte cr = 0x0D, lf = 10 -- byte constants
const word cr = 1492          -- word constant

-- Literal (SDWORD) constant
const seconds_per_day = 60 * 60 * 24

-- constant table
const byte mytable[5] = {"M","2",24,1,43}
-- String constant table
const byte zz[] = "Hello"

-- Extended type constant
const byte*3 my_pointer = 0xFFCC00
```

[4] See section 1.6.1 on page 19

1.5 Variables

1.5.1 Declaration

A variable declaration introduces a name which will be used within the *JAL 2.0* program. In PIC architecture this name will correspond to a hardware location called *register* located in RAM memory.

These *registers* can be of two types:

- GPR. General Purpose Registers
- SFR. Special Function Registers

Optionally the name can be bound to a specific location[5], or to other already declared variable[6], otherwise the compiler allocates a suitable and available GPR location.

In a declaration a value can be assigned to a variable, which has the same effect as an equivalent assignment immediately following the declaration.

Example:

```
 var byte demo = 0xAF

--  ... same as ...
var byte demo
demo = 0xAF
```

The initial value does not need to be a constant expression.

JAL 2.0 will set the correct bank memory while addressing a variable (except in inline assembler[7]).

```
VAR [VOLATILE] type[*cexpr]
  identifier [ '[' cexpr ']' ]

  [ { AT cexpr [ : bit ] |
        variable [ : bit ] |
       '{' cexpr1[, cexpr2...] '}'
```

[5] See section 1.5.2 on page 18
[6] See section 1.5.4 on page 19
[7] See section 1.11 on page 34

```
  | IS variable }

[ '=' cexpr | '{' cexpr1, ... '}' | '=' '"' cexpr '"']

[, identifier2...]
```

VAR denotes the beginning of a variable definition clause.

VOLATILE A variable can be declared volatile, which expresses that the variable does not possess normal variable semantics[8].

type[*cexpr] The *type* of the variable[9].

Identifier Any valid *JAL 2.0* identifier.

'[' cexpr ']' Defines a table[10] of *cexpr*[11] elements. The table index starts at 0 and continues through (cexpr - 1). cexpr must be >= 1. A table *MUST* fit entirely within a single PIC data bank.

AT ... denotes the location of the variable[12].

IS variable Tells the compiler that this identifier is simply an alias for another[13].

'=' expr Shorthand assignment. The variable will be assigned expr.

'=' '{' expr1 [, expr2 ...] '}' For a table variable, the elements will be assigned expr1, expr2, ...

"" cexpr "" A *string* constant can be assigned to a variable table:
`var byte x[5] = "hello".`

, identifier2 ... Allows defining multiple variables with the same attributes: VAR BYTE a,b,c

[8] See section 1.5.3 on the next page
[9] See section 1.2.1 on page 12 and section 1.2.2 on page 12.
[10] See section 1.6.2 on page 20.
[11] *cexpr* means a constant expression or a literal value.
[12] See section 1.5.2 on the next page
[13] See section 1.5.4 on page 19

```
 var byte x, y=3
var word z
var dword i=0
var byte AD_lo, AD_hi
var word AD_result = AD_lo + 256*AD_hi
```

1.5.2 Location

A variable declaration can specify the adress of the variable. The address expression must be compile-time constant. The compiler takes care of the translation to the banked address.

AT cexpr [':' bit] Places the new variable at address *cexpr*.

AT variable [':' bit] Places the new variable at the same address as an existing variable. Any address uses for explicit placement will not be allocated to another variable.

AT '{' cexpr1[, cexpr2 . . .] '}' Places the new variable at multiple address. On the PIC, many of the special purpose registers[14] are mirrored in two or more data banks. Telling the compiler which address hold the variable allows it to optimize the data access bits.

```
var byte volatile porta at 0x06
var volatile byte _status AT {0x0003, 0x0083,
                              0x0103, 0x0183}
var bit  volatile _z at _status : 2
```

1.5.3 Volatile

The *VOLATILE* keyword guarantees that a variable that is either used or assigned will not be optimized away, and the variable will be only read once when evaluating an expression. Normally, if a variable is assigned a value that is never used, the assignment is removed and the variable will not allocated any space.

If the assignment is an expression, the expression *will* be fully evaluated. If a variable is used, but never assigned, all instances of the variable *will* be replaced with the constant 0 (of the appropriate type) and the variable *will not* be allocated any space.

SFR's should always be declared as *VOLATILE*, as these are associated with certain hardware functions specific to the PIC being used.

[14] SFRs in Microchip™'s terminology.

```
var volatile byte FSR at 4
var volatile byte INDF at 0
var volatile byte count
```

1.5.4 Alias

A variable can be declared to be an alias for another variable. This is used much like a constant declaration to hide the actual identity of an identifier from subsequent code.

```
-- fragment of a library file,
-- which defines the pins used by the library
var byte volatile i2c_clock    is pin_a3
var byte volatile i2c_data_in  is pin_a4
var byte volatile i2c_data_out is pin_a4_direction
```

1.6 Tables

1.6.1 Constant tables

Constant tables are stored in program code, they're limited to 255 values.

```
const byte msg[5] = {"M","2",24,1,43}
```

A constant table will produce no code unless it's used with a variable subscript. So, if you use:

```
-- Constant index:
-- "msg[3]" will replace by the corresponding
-- literal value, like: a=1
a = msg[3]
```

... the constant value *1* will be assigned into variable *a*. And if you use:

```
-- Variable index:
-- A special look up table function is built
x = 3
a = msg[x]
```

... *msg* will become a lookup table function that will return the desired value.

If constant table is declared with values assignment, it's not necessary to include the table *index:*

```
const byte msg[] = {"M","2",24,1,43}
```

In order to know the amount of values in the table you must use the COUNT statement[15].

1.6.2 Variable tables

Variable tables are stored in RAM memory and must fit within a single bank.

```
var byte msg[5] = {"M","2",24,1,43}
```

1. when *defining* a table, the size must be const, so
   var byte myvar[3] ; this is valid
   var byte myvar[n] ; this is *NOT* valid if *n* is a variable
2. when *using* the table, the index can be either const or a variable. The table starts at index 0. When using a variable, no bounds checking is done.

```
-- Constant index:
-- "msg[3]" will replace by the exact file register
-- with the index 3
a = msg[3]

-- Variable index:
-- An INDIRECT MEMORY ACCESS is used to get the value
x = 3
a = msg[x]
```

If variable table is declared with values assignment, it's not necessary to include the table *index:*

```
var byte msg[] = "Hello"
```

In order to know the amount of values in the table you must use the COUNT statement[16].

[15] See section 1.8.7 on page 27
[16] See section 1.8.7 on page 27

1.7 Expressions

An expression is constructed from literals, identifiers, function calls and operators. An identifier can identify a constant, a variable or (within a subprogram) a formal parameter.

1.7.1 Operators

The following operators are defined in *JAL 2.0* (ordered by priority):

Op.	Description	Priority	Example
`!!`	Logical	0 (highest)	`!!5 = 1` `!!0 = 0`
`-`	Unary negation	0 (highest)	`-1 -- negative`

`!`	Bitwise complement	0 (highest)	`var byte a=0b_0000_1111`
			`a=!a`
			`-- a=0b_1111_0000`

`~`	Bitwise complement	0 (highest)	`var byte a=0b_0000_1111`
			`a=~a`
			`-- a=0b_1111_0000`

`*`	Multiplication	1	`var byte a = 2` `a=a*3 -- a=6`
`/`	Integer division	1	`var byte a = 17` `a=a/2 -- a=8`
`%`	Modulus division	1	`var byte a = 17` `a=a%2 -- a=1`
`+`	Addition	2	`var byte a = 2` `a=a+3 -- a=5`
`-`	Subtraction	2	`var byte a = 17` `a=a-10 -- a=7`
`<<`	Left shift	3	`var byte a = 0x81` `a=a<<1 -- a=0x02`
`>>`	Right shift	3	`var byte a = 0x82` `a=a>>1 -- a=0x41`
`<`	Less than	3	`var byte a=12, b=14` `if a < b then ...`
`<=`	Less or equal than	3	`var byte a=12, b=12` `if a <= b then ...`
...			

Op.	Description	Priority	Example
==	Equal	3	`var byte a=12, b=12` `if a == b then ...`
!=	Not equal	3	`var byte a=12, b=14` `if a != b then ...`
>=	Greater or equal than	3	`var byte a=14, b=12` `if a >= b then ...`
>	Greater than	3	`var byte a=12, b=12` `if a >= b then ...`

&	Bitwise AND	4 (lowest)	`var byte a=0b_1111_1110`
			`a=a&0b_0000_0011`
			`-- a=0b_0000_0010`

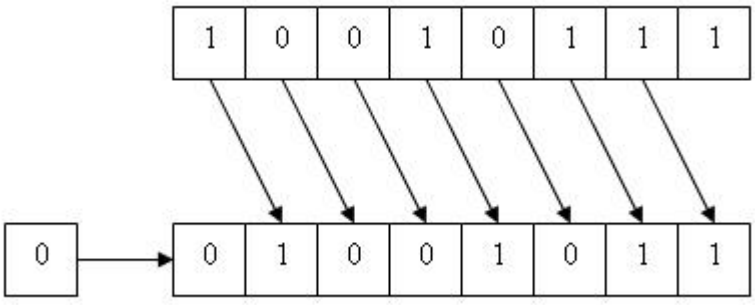
|	Bitwise OR	4 (lowest)	`var byte a=0b_0000_1110`
			`a=a|0b_0011_1100`
			`-- a=0b_0011_1110`

^	Bitwise XOR	4 (lowest)	`var byte a=0b_1111_1110`
			`a=a^0b_0000_0011`
			`-- a=0b_1111_1101`

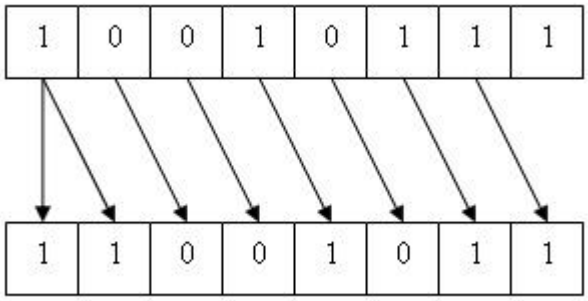
Tips:

- The *Logical* operator "!!" returns 0 if the operand is 0, or 1 if the operand is not 0. It's useful in some expressions which need a guarantee that operand is either 1 or 0.
- Right shift is logical for unsigned types, and arithmetic for signed types (it's sign preserving).

Logical right shift (for unsigned types):



Arithmetic right shift (for signed types):



- Operands to binary operations *MUST* be the same, and return the type of the operand *EXCEPT* the relationals (">=", "<", etc.), which return a BIT value.

Example:

```
 -- Use of relationals as BIT type selector:
const myclk = 1 * ( SPI_clock == (target_clock / 4)  ) +
              2 * ( SPI_clock == (target_clock / 16) ) +
              3 * ( SPI_clock == (target_clock / 64) )
 -- myclk being assigned 1, 2, 3, or 0.
```

- An exception to the above rule is the universal type : when used in an expression, the universal type will be converted to type of the other operand.

Example:

```
var byte a = 1 << n
if ( a > b ) | ( c < d ) | ( x != y ) then
   x = ( x & 0b_1100_0011 ) | 0b_0001_0100
end if
```

1.7.2 Priority

Braces can be used to force the association, otherwise the operator's associate with their arguments according to operator's priority.

Example:

```
var byte x = ! a + b  -- ( ! a ) + b
var y = ! ( a + b )   -- not the same as previous
```

1.8 Statements

A statement is any variable, constant, function, or procedure definition, assignment, control (IF) or looping (FOR, FOREVER, WHILE).

1.8.1 Declaration

Declarations are considered statements, so declarations can appear anywhere in a program where a statement is allowed.

Example:

```
a = 5
-- need a few locals here? no problem!
var byte x = 1, y = 0
while x < a loop
   y = y + x
   x = x + 1
end loop
```

1.8.2 Assignment

An assignment statement evaluates the expression and assigns its value to the variable or formal parameter indicated by the name on the left of the assignment.

Example:

```
var byte a
procedure p( byte out q ) is
   q = 5 -- assign to the (out) parameter q
   a = 4 -- assign to the global variable a
end procedure
a = 5 -- assign to the (now local) variable a
```

1.8.3 IF

An *IF* statement evaluates an expression. If the result is true the list of statements following the *THEN* token is executed.

Before the *ELSE* token any number of *ELSIF* tokens can appear. When the *IF* condition is false, the first *ELSIF* condition is evaluated. If it is true the corresponding statements are executed, otherwise execution continues with the next *ELSIF* part.

When none of the *IF* and *ELSIF* conditions evaluate to true the statements in the optional *ELSE* part are executed.

The IF statement serves two purposes:

Conditional execution

```
IF expr THEN
   block
[ ELSIF expr THEN block ... ]
[ ELSE block ]
END IF
```

Note: any number of ELSIF conditions may be present.

Example:

```
IF myvar = 13 THEN
   -- Case of myvar = 13 ...
ELSIF myvar = 10 THEN
   -- Case of myvar = 10 ...
ELSE
   -- Any other values of myvar
END IF
```

Conditional compilation

```
IF cexpr THEN
   block
[ ELSIF cexpr THEN block ...]
[ ELSE block ]
END IF
```

In this case, a new scope is *NOT* opened. If *cexpr*[17] is 0, the associated statements are skipped without further processing, so it can be used to create a block comment.

Example:

[17] *cexpr* means a constant expression or a literal value.

```
IF target_chip = 16f877 THEN
   -- Execution part if PIC16F877
ELSIF target_chip = 16f876 THEN
   -- Execution part if PIC16F876
ELSE
   -- Execution part other chips
END IF
```

1.8.4 WHILE

The WHILE statement allows conditional looping.

```
WHILE expr LOOP
   block
END LOOP
```

A while statement evaluates the expression (*expr*). If the result is false, the while statement has completed its execution. Otherwise the statements are executed, after which the expression is evaluated again etc. The *block* statements will be executed as long as *expr* is non-0

Example:

```
while r > y loop
   d = d + 1
   r = r - y
end loop
```

1.8.5 FOR

The FOR statement allows looping a given number of times.

```
FOR expr [ USING variable ] LOOP
   block
END LOOP
```

If the *USING variable* clause does not exist, the variable *_temp* is used instead of. If *_temp* is needed, its type will be the same type as *expr*.

1.8.6 FOREVER

The *FOREVER* statement simply creates a loop that will never end.

```
FOREVER LOOP
   block
END LOOP
```

1.8.7 COUNT

The COUNT statement returns the number of elements of an *array*, can be used anywhere a constant is expected:

```
-- using constant tables
const byte x[] = "hello"
var byte y
var volatile byte z

for count(x) using y loop
   z = x[y]
end loop

-- using variable tables
var byte m[] = "hello"
var byte n
var volatile byte p

for count(m) using n loop
   p = m[n]
end loop
```

1.8.8 _usec_delay

The _USEC_DELAY creates an inline delay.

```
_usec_delay(cexpr)
```

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[18] *cexpr* means a constant expression or a literal value.

For clock speeds 4MHz and higher, the delay is exact assuming interrupts are not enabled. A previous `pragma target clock ...` *pragma statement* is required, or the error *target_clock not found* will be generated. The longest delay available is about 35 minutes, but this requires 5K code at 20MHz.

```
_usec_delay(1000)  -- 1 msec delay with a 4MHz Xtal.
```

1.9 Procedures and functions

A procedure is a named block of statements that may take parameters.

A function is like a procedure, the difference is it will return a single value which can be used in an expression.

```
PROCEDURE identifier
      [ '(' [[VOLATILE] {IN | OUT | IN OUT } param
            [, ...]] ')' ]
      IS [ BEGIN ]

   block

END PROCEDURE


FUNCTION identifier
      [ '(' [[VOLATILE] {IN | OUT | IN OUT } param
            [, ...]] ')' ]
      RETURN type IS [ BEGIN ]

   block
   RETURN expr

END FUNCTION
```

Note : The identifier used to denote a *PROCEDURE* or *FUNCTION* belongs to the outer block, whereas all parameter names will belong to a newly created block Using of *[BEGIN]* is optional.

PROCEDURE denotes the beginning of a procedure definition.

FUNCTION denotes the beginning of a function definition.

identifier Any legal *JAL 2.0* identifier.

VOLATILE A volatile parameter must be passed in as a *pseudo-variable*[19]. If the parameter passed in is regular variable, an appropriate p*seudo-variable* will be created.

IN On entry, this parameter's value is set by the caller to an expression. If this parameters is not VOLATILE, it can be used or modified like any other variable, but changes will not be passed back to the caller. If this parameter is VOLATILE, its value cannot be written.

Example:

```
procedure ex_in( byte in x ) is
    x = x + 1
 end procedure

 -- running the procedure:
 ex_in (0x0A)
 -- will compute inside the block x = 0x0B,
 -- there is no access outside the block to the x value
```

OUT On entry, this parameter's value is not defined. The caller *MUST* pass a variable (not a constant or expression). If this parameter is not VOLATILE, it can be used or modified like any other variable. If the parameters is VOLATILE, its value cannot be read. On exit, the caller's variable will be set to whatever value this has.

Example:

```
procedure ex_out( byte out x ) is
    x = 0x0A
 end procedure

 -- running the procedure:
 var byte a = 0
 ex_out(a)
 -- by using the procedure, a = 0x0A
```

[19] See section 1.9.1 on page 31

IN OUT This combines properties of IN and OUT.

Example:

```
procedure ex2_in_out( byte in out x ) is
   x = x + 1
end procedure

-- before running the procedure:
var byte mydata = 0x0A

-- after running the procedure:
ex2_in_out (mydata)
-- mydata will be 0x0B
```

param This is defined *exactly* like a variable definition above, except the *VAR* keyword is not expected and it cannot be assigned a value.

RETURN type For functions, this defines the type returned to the caller. type can be any standard type, including the width specifier.

Example:

```
function compute_AD_result
                   (byte in AD_hi,
                    byte in AD_lo) return word is

   AD_result = AD_lo + 256*AD_hi
   return AD_result
end function

compute_AD_result ( 0b_0000_0011, 0b_1111_1111 )
-- will return the value AD_result = 1023
```

RETURN expr In a function, the *RETURN expr* statement is used to set the value returned. If no *RETURN expr* is used in a function, the return value will be undefined.

IS [BEGIN] Starts the statement block.

block Any group of statements.

END {PROCEDURE | FUNCTION} Terminates the statement block.

Note: PROCEDUREs and FUNCTIONs can be nested.

1.9.1 Pseudo variables

Pseudo-variables are procedures and/or functions that are references like and act like variables. The accessor of a pseudo variable is a function that takes no parameters.

```
FUNCTION a'get RETURN type IS
   block
END FUNCTION
```

Now, any reference to *a* will be replaced with a call to *a'get.*

Similarly, to set a pseudo variable, define a procedure that takes one parameter.

```
PROCEDURE a'put ( param ) IS
   block
END PROCEDURE
```

Now, any assignment to *a* will be replaced with a call to *a'put*.

If an appropriate pseudo-variable is not found, an attempt is made to find the variable itself (eg, when used in an expression, first a search is made on *a'get()*, failing that a search is made for the variable *a*.

If more than one of the variable or accessor functions and/or variable are defined, all must be of the same type!

Example:

```
procedure hd44780'put( byte in x ) is ...

-- using the procedure
hd44780 = "H"
hd44780 = "e"
hd44780 = "l"
```

```
hd44780 = "l"
hd44780 = "o"

procedure async'put( byte in x ) is ...

-- using the procedure
async = "H"
async = "e"
async = "l"
async = "l"
async = "o"

function async'get return byte is ..

-- using the function:
x = async
```

1.10 Tasks

A *TASK* is a *procedure* that is started and becomes an apparently parallel thread of execution. *JAL 2.0* implements *co-operative multitasking*, that each *Task* uses a special command to hand back program thread to the scheduler, which starts the oldest suspended task from the point it made that command.

A *Task* has the same format as a *PROCEDURE*[20] (it can take any number of parameters), the format is:

```
TASK name [ (parameters) ] IS
END TASK
```

Tasks are started with:

```
START name[(parameters)]
```

And suspended with:

```
SUSPEND
```

[20] See section 1.9 on page 28.

If a *Task* reaches the `"END TASK"`, it is killed.

Limitations:

- There is currently no way to determine a particular *Task*'s ID, how many *Tasks* are running, or if *Task* creation fails.
- There's also no way to kill a *Task* from another *Task*.
- *SUSPEND* is only allowed in the *Task* itself (not in anything called by the *Task*).
- Each *Task* has its own variable storage (just like any other procedure or function).
- If the main program comes to the end, it still sleeps as before, effectively killing all running *Tasks*.
- If you have two copies of the same *Task* running, bad things happen, so don't do that (actually, nothing really bad happens, they simply behave like a single *Task* occupying to slots in the task list).
- You don't know the execution order of *Tasks*, and you don't know if a *Task* will execute immediately after the START or wait until the first SUSPEND.

Example:

Three *Tasks*:

- Task1 increments *counter1*.
- Task2 increments *counter2*
- main task simply loops.

```
VAR VOLATILE BYTE counter1
VAR VOLATILE BYTE counter2

TASK task1(BYTE in aa) is
   counter1 = aa
   FOREVER LOOP
      counter1 = counter1 + 1
      SUSPEND
   END LOOP
END TASK

TASK task2(BYTE in aa) is
```

```
   counter2 = aa
   FOREVER LOOP
      counter2 = counter2 + 1
      SUSPEND
   END LOOP
END TASK


START task1(10)
START task2(20)
FOREVER LOOP
   SUSPEND
END LOOP
```

1.11 Inline assembler

There is a full assembler available when needed, it can be accessed using two ways.

1.11.1 Single assembler statement

A simple assembler statement consists of the token "asm" followed by a single assembler statement.

Example:

```
asm clrwdt -- single assembler statement
```

1.11.2 Assembler block

A full assembler statement consists of the token "assembler", a sequence of label declarations, labels and assembler statements, and is terminated with the token token "end assembler".

```
ASSEMBLER
[LOCAL label[, label2...]]
[label:]
   [ { BANK | PAGE } ] asm statement
   ...
END ASSEMBLER
```

Any labels used as the destination of a CALL or GOTO must be defined in the LOCAL clause.

If the assembler statement accesses a file register and the BANK mnemonic is used, the appropriate statements will be generated to guarantee the correct data bank is accessed[21].

Example:

```
asm bank clrf myvar ; will set the correct bank of "myvar"
```

If the assembler statement jumps to a label and the PAGE mnemonic is used, the appropriate statements will be generated to guarantee the correct code segment is used[22].

Example:

```
asm page goto mylabel ; will set the correct page of "mylabel"
```

The full list of assembly statements defined in the PIC16F877/88 data sheet have been implemented using the syntax found therein.

OPCODE field description

f	Register file address (0x00 to 0x7F)
w	Working register (accumulator)
b	Bit address within an 8 bit file register
k	Literal field
d	Destination select: d=w: store result in *W*, d=f: store result in *f*, default d=f

Assembler statements set summary

Mnemonic	Description	Cycles	Flags affected
Byte-oriented file register operations			
ADDWF f,d	add *W* and *f*	1	C,DC,Z
ANDWF f,d	AND *W* and *f*	1	Z
CLRF f	Clear *f*	1	Z
CLRW	Clear *W*	1	Z
COMF f,d	Complement *f*	1	Z
DECF f,d	Decrement *f*	1	Z
DECFSZ f,d	Decrement *f*, skip if 0	1(2)	
...			

[21] See PRAGMA KEEP BANK in section 1.12 on page 37
[22] See PRAGMA KEEP PAGE in section 1.12 on page 37

Mnemonic	Description	Cycles	Flags affected
INCF f,d	Increment *f*	1	Z
INCFSZ f,d	Increment *f*, skip if 0	1(2)	
IORWF f,d	Inclusive OR *W* with *f*	1	Z
MOVF f,d	Move *f*	1	Z
MOVWF f	Move *W* to *f*	1	
NOP	No operation	1	
RLF f,d	Rotate left *f* through *carry*	1	C
RRF f,d	Rotate right *f* through *carry*	1	C
SUBWF f,d	Subtract *W* from *f*	1	C,DC,Z
SWAPF f,d	Swap nibbles in *f*	1	
XORWF f,d	Exclusive OR *W* with *f*	1	Z
Bit-oriented file register operations			
BCF f,b	Bir clear f	1	
BSF f,b	Bit set f	1	
BTFSC f,b	Bit test f, skip if clear	1(2)	
BTFSS f,b	Bit test f, skip if set	1(2)	
Literal and control operations			
ADDLW k	Add *literal* and *W*		C,DC,Z
ANDLW k	AND *literal* with *W*		Z
CALL k	Call subroutine		
CLRWDT	Clear watchdog timer		!TO,!PD
GOTO k	Go to address		
IORLW k	Inclusive OR *literal* with *W*		Z
MOVLW k	Move *literal* to *W*		
RETFIE	Return from interrupt		
RETLW k	Return with *literal* in *W*		
RETURN	Return from subroutine		
SLEEP	Go into standby mode		!TO,!PD
SUBLW k	Subtract *W* from *literal*		C,DC,Z
XORLW k	Exclusive OR *literal* with *W*		Z
Macros and extra mnemonics			
OPTION k	Move *literal* to *OPTION* register	1	
TRIS {5,6,7}	Move *W* to *TRIS {5,6,7}* register	1	
MOVFW f	A synonym for MOVF *f*, *W*	1	Z
SKPC	A synonym for BTFSS *_status*, *_c*	1(2)	
SKPNC	A synonym for BTFSC *_status*, *_c*	1(2)	
SKPZ	A synonym for BTFSS *_status*, *_z*	1(2)	
...			

Mnemonic	Description	Cycles	Flags affected
SKPNZ	A synonym for BTFSC *_status*, *_z*	1(2)	

1.11.3 Scope

An assembly statement can access any variable in scope. Only the simple types BIT, BYTE, SBYTE and ARRAY are supported.

If the variable is a table, you must take care of:

- The elements of a table can only be accessed using a constant subscript: `movf x[3],w`
- Constant tables must be treated as *literals*: `movlw x[3]`
- Variable tables must be treated as *file registers*: `movf x[3],w`

Example:

```
var byte x[]="hello"
var bit cc = low
var byte a
assembler
local 10:
   movf  x[3],w
   movwf a
   btfss cc
   goto  10
   incf  a,f
 10:
   nop
end assembler
```

1.12 Pragmas

The user pragmas – compiler directives – are those most likely to be used by the average user.

PRAGMA EEDATA cexpr1[, cexpr2...] Defines data to be stored in the EEPROM. This data always begins at the first location in the EEPROM. Each extra *expr* (or PRAGMA EEDATA) bumps the next usable location. If the EEPROM over fills, an error is generated[23].

Example:

```
pragma eedata "O","K",13,10,25
```

PRAGMA ERROR Generates an error. Useful for the conditional compilation with the IF statement.

PRAGMA INTERRUPT This must only be used inside a PROCEDURE whose execution is triggered by the reception of an interrupt. This procedure can take no parameters.
Using PRAGMA INTERRUPT links this procedure into the interrupt chain. Any number of procedures can exist in the interrupt chain, but the order in which they are executed is not defined.
No extra stack space is required by an interrupt entry point. Once a procedure has been marked as an interrupt entry point it cannot be directly called by the program.

Example:

```
var word cc, bb

procedure ISR_TMR0 is
pragma interrupt        -- This procedure is an
                        -- interrupt service routine
   if T0IF then         -- Check if TMR0 int.
      T0IF = low
      cc = cc + 1
   end if
end procedure

procedure ISR_TMR1 is
pragma interrupt        -- ... another one

   if TMR1IF then       -- Check if TMR1 int.
      TMR1IF = low
      bb = bb + 1
```

[23] See PRAGMA EEPROM in section 1.12.1 on page 41

```
      end if
   end procedure

cc=0
bb=0
```

PRAGMA JUMP_TABLE This is obsolete and simply issues a warning. It has been replaced by constant arrays.

PRAGMA KEEP [BANK] | [PAGE] When using inline assembly, or assembly blocks, this instructs the compiler to not optimize away any bank or page selectors generated. Without this, the compiler will normally not generate the selectors if the selector state is known to be correct.

PRAGMA NAME name Generates an error if the name the file being compiled is the same as name (what possible use is this?).

PRAGMA TARGET CHIP ident ident must be defined in `chipdef.jal` (see the list of variables beginning with `pic_*`).

Example:

```
PRAGMA TARGET CHIP 16f877
```

PRAGMA TARGET CPU ident ident must be defined in `chipdef.jal` .
This is analogous to: `CONST target_cpu = cpu_ident`.
PRAGMA TARGET CPU can overwrite the *CONST TARGET_CPU* definition.

Example:

```
CONST target_chip = pic_14
```

PRAGMA TARGET CLOCK cexpr Set the clock speed to cexpr. This is not used internally by the compiler.
This is analogous to: `CONST target_clock = cexpr`.
PRAGMA TARGET CLOCK can overwrite the *CONST TARGET_CLOCK* definition.

Example:

```
CONST target_clock = 10_000_000
```

PRAGMA TARGET FUSES cexpr1 cexpr2 Set the PIC configuration word register —denoted by the index *cexpr1*— with value *cexpr*2. The literal *cexpr1* must be in the range denoted by the index defined in pragma `CONST WORD _FUSES_BASE`.
Example:

```
PRAGMA TARGET fuses 0 0b_xx_xxxx_xxxx_xxxx
-- will set fuses once according to
-- first configuration word register
```

CONST WORD _FUSES '[' cexpr1 ']' '=' '{' cexpr2 ',' ... '}' Set the values of a multi-word configuration fuses, *cexpr1* denotes the ammount of words.

Example:

```
const word _fuses[2] = {0x3fff,0x3fff}
```

CONST WORD _FUSES_BASE '[' cexpr1 ']' '=' '{' cexpr2 ',' ... '}' Set the addresses of a multi-word configuration fusess, *cexpr1* denotes the ammount of words.

Example:

```
const word _fuse_base[2] = {0x2007, 0x2008}
```

PRAGMA TARGET fusedef tag This allows one to set a fuse based on chip mnemonics[24].

Available pragma target fuses defined are:

```
PRAGMA TARGET PROTECTION {on|off}
-- ON = flash program memory code protected
-- OFF = flash program memory code unprotected

PRAGMA TARGET DEBUG {on|off}
-- ON = In Circuit Debugger enabled
-- OFF = ICD disabled

PRAGMA TARGET CDP {on|off}
-- ON = data eprom code protected
```

[24] See PRAGMA FUSE_DEF in section 1.12.1 on the facing page

```
-- OFF = data eprom code unprotected

PRAGMA TARGET LVP {on|off}
-- ON =  low voltage ICSP enabled
-- OFF = low voltage ICSP disabled

PRAGMA TARGET BOR {on|off}
-- ON =  brown out reset enabled
--       (check PIC voltage greater
--        than BOR defined level)
-- OFF = brown out reset disabled
--       (PIC may run at less than
--        BOR defined level)

PRAGMA TARGET POWERUP {on|off}
-- ON = powerup delay enabled
--      ( add about 72mS delay after power+
--        up until program start)
-- OFF = powerup delay disabled

PRAGMA TARGET WATCHDOG {on|off}
-- ON = watchdog enabled
--      (watchdog delay period must be
--       programmed in the postscaler reg.)
-- OFF = watchdog disabled

PRAGMA TARGET OSC {lp|xt|hs|rc}
-- lp = low power oscillator,
--      use it with 32.768KHz to 200KHz crystal
-- xt = crystal/resonator 1MHz up to 4MHz
-- hs = high speed crystal/resonator 4MHz-20MHz
-- rc = resistor/capacitor oscillator
```

1.12.1 Chip Definition Pragmas

Internally the compiler doesn't know anything about the various chips. Instead, a chip definition file is used which describes code size, stack depth, eeprom location, general file register locations, etc.

Since these are only useful for those defining new chips, they're included here.

PRAGMA CODE cexpr Defines the maximum code size in words. If the total code generated exceeds this size an error is generated.
This is analogous to: `CONST _code_size = cexpr`.
PRAGMA CODE can overwrite the *CONST _CODE_SIZE* definition.

Example:

```
PRAGMA CODE 8192
```

PRAGMA DATA cexpr[-cexpr1][, . . .] This chip definition defines the data area available for variables (also known as the general file register areas).

Example:

```
pragma data  0x0020-0x007f, 0x00a0-0x00ff,
             0x120-0x16f, 0x1a0-0x1ef
```

PRAGMA EEPROM cexpr1, cexpr2 This is a chip definition PRAGMA and sets the start and size of the EEPROM (*cexpr1* is the start, *cexpr2* is the size). If any *PRAGMA EEDATA* statements exist, the assembly file will include:

```
pragma eeprom 0x2100, 256

ORG 0x2100
DW a, b, c, ...  ; PRAGMA EEDATA values
```

PRAGMA STACK cexpr Defines the maximum stack size in levels. If the total stack use is determined to be greater than this, an error is generated.
This is analogous to: `CONST _stack_size = cexpr`.
PRAGMA STACK can overwrite the *CONST _STACK_SIZE* definition.

Example:

```
pragma stack  8
```

PRAGMA FUSE_DEF tag [':' cexpr1] mask '{' tag '=' cexpr2 . . . '}' This defines a fuse mnemonic that can be used to set and clear bits based on names rather than numbers. The *cexpr1* denotes the index of a *multi-word configuration table*.

Example:

```
   pragma fuse_def protection 0b10000000000000 {
      on = 0b00000000000000
      off = 0b01000000000000
   }

   pragma fuse_def FCMEN:1 0b0_0000_0000_0001 { -- At 2nd conf. word
      ENABLED  = 0b0_0000_0000_0001
      DISABLED = 0b0_0000_0000_0000
}
```

This defines a target mnemonic that the would be used as follows:
`PRAGMA TARGET protection on`
or
`PRAGMA TARGET protection off`
Internally, it becomes: `_fuses = (_fuses & ~mask) | expr`

2 Compiler

2.1 Basic

The *JAL 2.0* compiler is a command-line tool[1]. The same compiler is available for the MS Windows command line, and for Linux[2].

After a successful compilation the *JAL 2.0* compiler produces two output files, these files will have the same basic name as the *JAL 2.0* file but the extensions will change to reflect their types. The base name (file name without extension) of these two files is the same of *JAL 2.0* program requested for compilation. The first output file has the extension `".hex"` and contains the hex dump of the compiled program. This file can be used directly with most programmers. The second file has the extension `".asm"` and contains the assembler (text) of the compiled program. This file can be used to inspect the generated code and to make small modifications. The assembler file can be assembled with the standard Microchip™[1] assembler.

Example:

Let's assume that `HOME_PJAL` directory (where *JAL 2.0* compiler is)[3]:

```
c:\pjal\pjal.exe
```

The required libraries are in the directory:

```
c:\pjal\chipdef\
```

On executing *JAL 2.0* it's suggested to include `chipdef` directory in the search path[4] [25]:

```
c:\pjal> pjal.exe -s c:\pjal\chipdef
```

Optionally, other user libraries can be nested:

```
c:\pjal> pjal.exe -s c:\pjal\chipdef;c:\pjal\lib
```

As well other command line switches[5]:

```
c:\pjal> pjal.exe -s c:\pjal\chipdef -long-star
```

[1] See section 2.2 on the next page
[2] Linux binary requires *libc.so.6* library.
[3] This example is valid for MS Windows compiler version. Linux users – they're supposed to be used to *shell* – can apply the same concepts.
[4] *JAL 2.0*compiler will search *chipdef* in current directory by default.
[5] See section 2.2 on the following page

Finally, include the desired *JAL 2.0* user file:

```
c:\pjal> pjal.exe -s c:\pjal\chipdef;c:\pjal\lib c:\pjal\test.jal
```

JAL 2.0 compiler will report the success of compilation:

```
c:\pjal> pjal.exe -s c:\pjal\chipdef;c:\pjal\lib c:\pjal\test.jal
picjal 0.9 (compiled Jan 19 2006)
generating p-code
0 errors, 0 warnings
3615 tokens, 28452 chars; 912 lines; 3 files
cmds removed: 9
generating PIC code pass 1
generating PIC code pass 2
writing result
Code area: 6 of 8192 used
Data area: 6 of 352 used
Software stack available: 96 bytes
Hardware stack depth 0

c:\pjal\
```

And on successful result, two new files will be created:

`c:\pjal\test.asm`

`c:\pjal\test.hex`

2.2 Command line compiler options

The compiler has a wealth of options to enable various debugging output[6].

Format: `pjal options`

-hex *arg* overrides the default name of the `".hex"` file.

-asm *arg* overrides the default name of the `".asm"` file.

-rickpic using with RICK FARMER's PIC loader. The preamble is:

```
org 3
goto xxx
```

-debug show debug information.

[6] See *Revision history* section for latest *JAL 2.0* version related with this document.

-quiet no status updates.

-s *arg* set the include path, elements separated with **";"**

-task *arg* turn on basic tasking, where *arg* is the maximum number of tasks that can run at a time. *Arg* must be >= 2 (since the main program is a task).

-pcode show pcode in the asm file.

-clear clears all user data areas on program entry (note: volatile, user-placed variables, and unused data areas are not cleared).

-no-expr-reduction do not perform expression reduction.

-no-cexpr-reduction do not perform constant expression reduction.

-nofuse do not put FUSES into the assembly or hex file.

-long-start force the first instruction to be a long jump. It is apparently the common bootloader requirement. The preamble is:

```
bcf _pclath, 4
bcf _pclath, 3
goto xxx
goto nop
```

-Wno-conversion turn off signed/unsigned conversion warning.

-Wno-truncate turn off possible truncation in assignment warning.

-Wno-warn turn off all warnings.

-nocodegen do not generate any assembly code.

-Wdirectives issue a warning when a compiler directive is found.

-warn-stack-overflow changes *hardware stack overflow* errors to warnings.

2.3 Behaviour

2.3.1 End of program.

In *JAL 2.0*, if the execution runs out of statements, the following lines are automatically included:

```
ASSEMBLER
 LOCAL label
 label:
   sleep
   goto label
END ASSEMBLER
```

... so one is guaranteed to never fall of the end off a program.

2.3.2 FOR without USING

If the token *USING variable* does not exist:

```
FOR expr LOOP
   block
END LOOP
```

... becomes:

```
_temp = 0
WHILE (_temp < expr) LOOP
   block
   _temp = _temp + 1
END LOOP
```

If the *USING variable* clause does exist, the *variable* is used instead of *_temp*. If *_temp* is needed, its type will be the same type as *expr*.

2.3.3 Optimization

In *JAL 2.0*, two internal counters are kept for each variable:

- assign_ct: the number of times a variable has been assigned a value
- use_ct: the number of times a variable's value appears in an expression

so, given the assignment: x = y

x's assign_ct is incremented, and *y*'s use_ct is incremented.

During the optimizer phase, if a variable's use_ct is zero (the variable never occurs on the right-hand side of an assignment, and is never passed to a procedure), any assignment to that variable is removed.

Also, if a variable's assign_ct is zero (the variable never occurs on the left-hand side of an assignment, and is not an IN parameter to a procedure), that variable is changed to type CONST and is assigned a value of 0.

If a variable is marked VOLATILE, this optimization doesn't occur because by definition a VOLATILE variable is both assigned and used (for example, a PIC register).

2.3.4 Debug output

```
cmd=0x004C79D8 op=18
...4c7988[B---1]:{4c78d8:_btemp0[B---:1]}
cmds removed: 11
```

These are debugging messages only. If you don't compile with `"-pcode"` and `"-debug"` you won't see them[7].

cmd=xxxx is the pcode cmd identifier

op=xx means this is an operator pcode (as opposed to a branching one)

nnnnn:'B—x' translates to:

- **nnnnn** : value identifier
- **B** boolean
- **C** constant
- **V** volatile
- **S** signed
- **x** width (a number)

The variable is also dumped. This information is useless unless you've the source code and a debugger available.

[7] See section 2.2 on page 46.

3 Libraries

3.1 PIC definition library structure

These libraries describes the core of some PIC chips in order to use inside a *JAL 2.0* program.

3.1.1 Chip definition file

The file "chipdef.jal" contains constants needed by *JAL 2.0*.

The constant values that are assigned by *JAL 2.0* to target_chip are:

```
const pic_16f877 = 1
const pic_16f628 = 2
const pic_16c84 = 3
const pic_16f84 = 4
const pic_12c509a = 5
const pic_12f675 = 6
const pic_18f242 = 7
const pic_18f252 = 8
const pic_18f452 = 9
const pic_SX18 = 10
const pic_SX28 = 11
const pic_SX = 12
```

Other constants defining different PICs may be added by the user, as long a *core definition* file[1] and a *PIC chip definition* file[2] are also generated.

The constant values that are assigned by *JAL 2.0* to target_cpu are:

```
const pic_12 = 1
const pic_14 = 2
```

[1] See section 3.1.2 on the following page
[2] See section 3.1.3 on page 55

```
const pic_16 = 3
const sx_12  = 4
```

Other constants used widely:

```
const bit  on    = 1
const bit  off   = 0
const byte w     = 0
const byte f     = 1
const bit  true  = 1
const bit  false = 0
const bit  high  = 1
const bit  low   = 0
```

JAL 2.0 control bit, only useful if you are sharing libraries with *JAL 2.0* and JAL:

```
const bit  PJAL  = 1
```

3.1.2 Core definition file

Describes internal hardware structure of a subset of Microchip ™ PICs. As reference, here is the `"c16f87x.jal"` file structure that covers all PIC16F87x subset.

In the first line must be an *include* to Core definition file[3]:

```
include chipdef
```

Following the type of CPU :

```
const target_cpu = pic_14
```

Number of Stack levels :

```
pragma stack  8
```

Configuration word address and default value :

[3] See section 3.1.1 on the preceding page

```
const word _fuses     = 0x3fff ; default value
const word _fuse_base = 0x2007 ; address
```

For PICs with several *configuration words* (ie: PIC16F88):

```
const word _fuses_ct             = 2
const word _fuses[_fuses_ct]     = {0x3fff, 0x3fff} ; default value
const word _fuse_base[_fuses_ct] = {0x2007, 0x2008} ; where to put it
```

Minimal set of SFRs needed by *JAL 2.0*. You are warned not to change names, these must begin with underscore:

```
var volatile byte _pic_isr_w
    at {0x007f, 0x00ff, 0x017f, 0x01ff }
var volatile byte _ind
    at {0x0000, 0x0080, 0x0100, 0x0180}
var volatile byte _pcl
    at {0x0002, 0x0082, 0x0102, 0x0182}
var volatile byte _status
    at {0x0003, 0x0083, 0x0103, 0x0183}
var volatile byte _fsr
    at {0x0004, 0x0084, 0x0104, 0x0184}
var volatile byte _pclath
    at {0x000a, 0x008a, 0x010a, 0x018a}
```

Bit position of *STATUS* flags :

```
const        byte _irp    = 7
const        byte _rp1    = 6
const        byte _rp0    = 5
const        byte _not_to = 4
const        byte _not_pd = 3
const        byte _z      = 2
const        byte _dc     = 1
const        byte _c      = 0
```

Details of *configuration word* fuses :

```
pragma fuse_def protection 0b11000000110000 {
on  = 0b00000000000000
```

```
off = 0b11000000110000
}

pragma fuse_def debug      0b00100000000000 {
on  = 0b00000000000000
off = 0b00100000000000
}

pragma fuse_def cdp        0b00000100000000 {
on  = 0b00000000000000
off = 0b00000100000000
}

pragma fuse_def lvp        0b00000010000000 {
on  = 0b00000010000000
off = 0b00000000000000
}

pragma fuse_def bor        0b00000001000000 {
on  = 0b00000001000000
off = 0b00000000000000
}

pragma fuse_def powerup    0b00000000001000 {
off = 0b00000000001000
on  = 0b00000000000000
}

pragma fuse_def watchdog   0b00000000000100 {
off = 0b00000000000000
on  = 0b00000000000100
}

pragma fuse_def osc        0b00000000000011 {
lp  = 0b00000000000000
xt  = 0b00000000000001
hs  = 0b00000000000010
rc  = 0x00000000000011
}
```

For PICs with several *configuration words* (ie: PIC16F88):

```
pragma fuse_def IESO:1 0b0_0000_0000_0010 {
   ENABLED  = 0b0_0000_0000_0010
   DISABLED = 0b0_0000_0000_0000
}

pragma fuse_def FCMEN:1 0b0_0000_0000_0001 {
   ENABLED  = 0b0_0000_0000_0001
   DISABLED = 0b0_0000_0000_0000
}
```

3.1.3 PIC chip definition file

This file describes an specific PIC chip, distinguishing it from the rest of PICs of the subset. As reference, here is the "`c16f877.jal`" file structure for PIC16F877 PIC chip.

In the first line must be an *include* to the *Core definition* file[4]:

```
include c16f87x
```

Following chip, RAM, ROM and EEPROM memory ranges :

```
pragma target chip 16f877
pragma data  0x0020-0x007f, 0x00a0-0x00ff,
             0x120-0x16f, 0x1a0-0x1ef
pragma code  8192
pragma eeprom 0x2100, 256
```

3.1.4 Example of usage

```
-- main program
-- This must be in first line
include c16f877

-- Clock frequency
const target_clock = 10_000_000

-- main program
```

[4]See section 3.1.2 on page 52

```
var volatile byte a

a = a + 1
```

Note: This small program compiles without errors.

3.2 Other libraries

At the time of writing the new *JAL 2.0* compiler there are few tested libraries available for use in your projects[5].

To solve this problem, you can:

- Write your own set of libraries and share those with pjal community – highly recommended –.
- Wait for someone to write a set of libraries – not recommended –.
- Modify earlier JAL[4, 6] libraries to use with *JAL 2.0* compiler and share those with pjal community – highly recommended –.
- Use STEF MIENTKI's libraries[7].

It's not the purpose of this manual to describe what should be a full set of useful libraries. Instead we offer some guidelines on how to code basic operations in a PIC and start to create libraries of your own.

3.2.1 Operating with digital I/O ports

PIC chips – like PIC16F877 – have several I/O ports you can handle in your code. In order to use them in *JAL 2.0* you will need to declare them:

```
-- remember to declare SRFs "volatile"
var volatile byte PORTB at {0x06,0x106}
```

Also you will need the TRIS registers:

```
-- remember to declare SRFs "volatile"
var volatile byte _TRISB at {0x86,0x186}
```

[5] See *Revision history* section *on page 7.*

Now you have a *basic* management of PIC ports.

```
PORTB = 0              -- Reset PORTB
_TRISB = 0b_0000_0000 -- All PORTB output
PORTB = 0b_0001_0001  -- Set b4 and b0
PORTB = 0b_0000_1001  -- Clear b4, Set b3 and b0
```

In order to manage the *pins* (the bits) individually, firstly you must declare them:

```
var volatile byte PORTB at {0x06,0x106}
var volatile bit  pin_b0 at PORTB : 0
var volatile bit  pin_b1 at PORTB : 1
var volatile bit  pin_b2 at PORTB : 2
var volatile bit  pin_b3 at PORTB : 3
var volatile bit  pin_b4 at PORTB : 4
var volatile bit  pin_b5 at PORTB : 5
var volatile bit  pin_b6 at PORTB : 6
var volatile bit  pin_b7 at PORTB : 7

const bit input           = on
const bit output          = off

var volatile byte _TRISB at {0x86,0x186}
var volatile bit pin_b0_direction at _TRISB : 0
var volatile bit pin_b1_direction at _TRISB : 1
var volatile bit pin_b2_direction at _TRISB : 2
var volatile bit pin_b3_direction at _TRISB : 3
var volatile bit pin_b4_direction at _TRISB : 4
var volatile bit pin_b5_direction at _TRISB : 5
var volatile bit pin_b6_direction at _TRISB : 6
var volatile bit pin_b7_direction at _TRISB : 7
```

Now you can manage pins in this way:

```
var bit mybit             -- declare a variable

PORTB = 0                 -- Reset PORTB
_TRISB = 0b_0000_0000     -- All PORTB output
pin_b0 = high             -- Set b0
pin_b4_direction = input  -- b4 I/O input
mybit = pin_b4            -- Read b4 and store in mybit
```

If this was a step you would frequently repeat, you would put it in a procedure:

```
function port_do_stuff return bit is
   PORTB = 0                  -- Reset PORTB
   _TRISB = 0b_0000_0000      -- All PORTB output
   pin_b0 = high              -- Set b0
   pin_b4_direction = input   -- b4 I/O input
   return pin_b4              -- Read b4 exit with value
end function
```

Whenever your program needs to execute the above steps just add:

```
var bit mybit              -- declare a variable

mybit = port_do_stuff      -- call the function and
                           -- store b4 in mybit.
```

at the appropriate places in your code.

3.2.2 Shadowing digital I/O ports

When you perform any operation with PIC registers, first the register is read, then it's modified and finally it is written back to the register. This is fine when dealing with normal registers and most SFRs. However, you can have problems with I/O ports. Why? Because when the PIC reads a port register, it reads the actual state of the pins, rather than the output latch. This can cause two problems:

1. If the pin is an input, then the input pin state will be read, the operation performed on it, and the result sent to the output latch. This may not immediately cause problems, but if that pin is made into an output later on, the state of the output latch may have changed from the time it was deliberately set by the code.

2. If the pin is defined as an output, the output latch and the actual pin should be in the same state. In practice sometimes they aren't. If you are driving a capacitive load, the pin will take time to respond as it charges and discharges the capacitor. A common problem occurs when using the pin is set or clear directly on a port.

In order to avoid this issue, it's common to use a *shadow register*. The *shadow register* is simply a ram location you reserve. All operations are performed on this register, and when you are

finished, you copy it to the port register. It's a bit more trouble, and it can slow things down a tiny bit, but the effort is worth it for reliable operation[6].

In order to implement this shadow registers using *JAL 2.0*, first you must declare these *shadow registers*:

```
-- shadow registers
-- may not be declared as volatile
var byte _port_b_buffer
```

Now, write the necessary code to write into these shadow *registers*:

```
procedure portb'put( byte in x) is
   _port_b_buffer = x     -- make changes into "shadows"
   portb = _port_b_buffer -- send them to real I/O port
end procedure
```

Now you have a basic management of digital I/O ports using *shadow registers*:

```
_TRISB = 0b_0000_0000   -- All PORTB output
portb = 0b_1111_0000    -- Set a value in Port B
```

In order to manage the *pins* individually using these *shadow registers*:

```
-- To read pins, take them from real I/O ports
-- not from shadow registers
var volatile bit pin_b0 at portb : 0

-- Once pin_b0 is declared, override "write assignment"
procedure pin_b0'put( bit in x at _port_b_buffer : 0 ) is
   portb = _port_b_buffer
end procedure
```

Now you can manage pins in this way:

```
var bit mybit              -- declare a variable

portb = 0                  -- Reset PORTB
_TRISB = 0b_0000_0000      -- All PORTB output
pin_b0 = high              -- Set b0
pin_b4_direction = input   -- b4 I/O input
mybit = pin_b4             -- Read b4 and store in mybit
```

[6]This is an extract of MICHAEL RIGBY-JONES explanation stored in PICList[8].

3.2.3 Disabling analog functions

All PIC chips that have an analog module have the corresponding pins associated with this module ready to work in *analog mode* on reseting the device. The reason is that if an analog voltage is applied at pin (configured in *digital mode*) may cause the input buffer to consume current that is out of device specifications.

If your application needs to work with these pins in *digital mode*, you must deactivate *analog mode* first.

To do this, you must locate the desired SFR location (see your PIC chip *datasheets*) and declare it:

```
var volatile byte ADCON0      at 0x1F
```

Next, configure this SFR with the desired value:

```
ADCON0 = 0x07
```

In order to make a library to be useful with different PIC chips, you can extend this for different chips:

```
procedure disable_a_d_functions is
   if TARGET_CHIP == 16f877 then
      var volatile byte _adcon0 at 0x1F
      _adcon0 = 0x07
   elsif TARGET_CHIP == 16f28 then
      var volatile byte _vrcon0 at 0x9F
      _vrcon0 = 0x07
   end if
end procedure

-- call the procedure to disable AD functions
disable_a_d_functions
```

In this case the expression "`IF ... ELSIF ... END IF`" is a conditional compilation, that is evaluated at compile time. For this reason, SFR is declared inside the "`IF ...`".

3.2.4 Configuring the Oscillator

All PIC chips works thanks to an oscillator. In nearly all PICs you must configure this element in the *configuration word*. The basic type oscillator is built around an inverter amplifier that

drives an external component (a crystal or resonator on the amplifier positive feedback loop and two capacitors connected between amplifier in/out to ground). Designing the elements of this oscillator must be done with care, as an analog device needs (the combination of the quartz quality factor, capacitor values and PCB route lenghts affects the amplitude oscillation, start up oscillator delay and oscillator supply current). For *PIC16F877*, configuring the oscillator it's easy:

```
-- config oscillator
pragma target osc xt

-- Fosc value
pragma target clock 4_000_000
```

Other PICs gives you several oscillator configurations, like *PIC16F628:*

Mode	Description
LP	Low-Power Crystal
XT	Crystal/Resonator
HS	High-Speed Crystal/Resonator
EC	IO on RA6 and External Clock on RA7
ER1	CLKOUT on RA6 and External Resistor on RA7
ER2	IO on RA6 and External Resistor on RA7
INTRC1	Internal oscillator with CLKOUT on RA6 and IO on RA7
INTRC2	Internal oscillator with IO on RA6 and RA7

Also, newer PICs have some specific SFRs to change the behaviour of the oscillator. When using these PICs, like *PIC16F88* (*PIC16F819*, *PIC16F688*, etc), you must take care of the default reset state values of these SFRs and initialize them in accordance with your hardware.

Example:

The OSCON register of *PIC16F88*.

	R/W	R/W	R/W	R/W	R	R/W	R/W
—	IRCF2	IRCF1	IRCF0	OSTS	IOFS	SCS1	SCS0
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0

Note: — = not used, R/W = read/write, R= read only

IRCF2 : IRCF1 : IRCF0 internal RC osc frequency select bits.

```
000 = 31.25KHz
001 = 125KHz
010 = 250KHz
011 = 500KHz
100 = 1MHz
101 = 2MHz
110 = 4MHz
111 = 8MHz
```

OSTS Oscillator start-up time-out bit.

```
1 = running from primary clock (OSC1-OSC2 device)
0 = running from secondary clock (T1OSO-T1OSI device)
    or internal RC oscillator
```

IOFS INTOSC frequency stable bit (read only).

```
1 = frequency is stable
0 = frequency is not stable
```

SCS1 : SCS0 Oscillator mode select bits.

```
00 = osc mode defined by FOSC<2:0> (configuration word 1)
01 = T1OSC used as system clock
10 = INTRC used as system clock
```

Example:

Configuration of the oscillator for *PIC16F88* as 4MHz internal RC oscillator and output frequency INTOSC/4 at pin RA6.

```
pragma target osc int_clko

-- OSCCON
var volatile byte OSCCON at 0x8F

-- INTRC=4MHz, Running from INTRC as secondary clock,
-- Stable frequency, Osc. defined by FOSC bits from
-- the configuration word
OSCCON = 0b_0110_0100
```

```
-- OSCTUNE
var volatile byte OSCTUNE at 0x90

-- Set default factory calibration
OSCTUNE = 0

-- Declare the frequency of the configured oscillator
pragma target clock 4_000_000
```

3.2.5 Making *JAL 2.0* to recognize your own PIC device

It is possible to add newer PIC devices to *JAL 2.0*, a brief description of related libraries is in previous chapter[7]. In order to do this job, you must take into account following notes:

- Current *JAL 2.0* version[8] only supports PIC14 architecture.
- The modified libraries will be overwriten by future *JAL 2.0* libraries.
- Future *JAL 2.0* versions can make your projects useless, since past changes no longer exist.
- There is no guarantee that your changes will work with your *JAL 2.0* version.
- Make a backup of whole `HOME_PJAL` directory prior to do anything.

In order to add your own favourite PIC device, you must edit `chipdef.jal`[9] and write the necessary lines for your desired new PICs[10]:

```
const pic_16f676 = 100
const pic_16f88 = 101
```

Allocated numbers should not overrides the old *target_chip* constant definitions. Save the `chipdef.jal` overwritting the old file.

Create a *core definition file* for your favourite PIC microcontroller inspiring yourself from the PIC datasheet and the already existing *core definition files*[11].

[7] See section 3.1 on page 51.
[8] See Revision History on page 7
[9] File located in `HOME_PJAL\chipdef\chipdef.jal`.
[10] See section 3.1.1 on page 51.
[11] See section 3.1.2 on page 52.

Example:

For the *PIC16F88* will look like this one:

```
; <c16f8x.jal> this is the name of the following file
include chipdef
;
; chip definition for the 16f87_16F88 series
const target_cpu = pic_14

var volatile byte _ind AT {0x0000, 0x0080, 0x0100, 0x0180}
var volatile byte _pcl AT {0x0002, 0x0082, 0x0102, 0x0182}
var volatile byte _status AT {0x0003, 0x0083, 0x0103, 0x0183}
var volatile byte _fsr AT {0x0004, 0x0084, 0x0104, 0x0184}

const byte _irp = 7
const byte _rp1 = 6
const byte _rp0 = 5
const byte _not_to = 4
const byte _not_pd = 3
const byte _z = 2
const byte _dc = 1
const byte _c = 0

var volatile byte _pclath AT {0x000a, 0x008a, 0x010a, 0x018a}

pragma stack 8

-- where to put config_words
const word _fuses[2] = {0x3fff,0x3fff} ; default value
const word _fuses_base[2] = {0x2007,0x2008}

pragma fuse_def protection 0b10_0000_0000_0000 {
   on = 0b00_0000_0000_0000
   off = 0b01_0000_0000_0000
}

pragma fuse_def ccp1       0b01_0000_0000_0000 {
   rb3 = 0b00_0000_0000_0000
   rb0 = 0b01_0000_0000_0000
}
```

```
pragma fuse_def debug      0b00_1000_0000_0000 {
   on  = 0b00_0000_0000_0000
   off = 0b00_1000_0000_0000
}

pragma fuse_def wrt      0b00_0110_0000_0000 {
   off     = 0b00_0110_0000_0000  ; write protection off
   on_00ff = 0b00_0100_0000_0000  ; 0000-00ff write protected
   on_07ff = 0b00_0010_0000_0000  ; 0000-07ff write protected
   on_0fff = 0b00_0000_0000_0000  ; 0000-0fff write protected
}

pragma fuse_def cdp        0b00_0001_0000_0000 {
   on  = 0b00_0000_0000_0000
   off = 0b00_0001_0000_0000
}

pragma fuse_def lvp        0b00_0000_1000_0000 {
   on  = 0b00_0000_1000_0000
   off = 0b00_0000_0000_0000
}

pragma fuse_def bor        0b00_0000_0100_0000 {
   on  = 0b00_0000_0100_0000
   off = 0b00_0000_0000_0000
}

pragma fuse_def mclr       0b00_0000_0010_0000 {
   on  = 0b00_0000_0010_0000
   off = 0b00_0000_0000_0000
}

pragma fuse_def powerup    0b00_0000_0000_1000 {
   off = 0b00_0000_0000_1000
   on  = 0b00_0000_0000_0000
}

pragma fuse_def watchdog   0b00_0000_0000_0100 {
   off = 0b00_0000_0000_0000
   on  = 0b00_0000_0000_0100
}
```

```
   pragma fuse_def osc        0b00_0000_0001_0011 {
      lp       = 0b0000000000_0000
      xt       = 0b0000000000_0001
      hs       = 0b0000000000_0010
      ecio     = 0b0000000000_0011
      int_io   = 0b0000000001_0000
      int_clko = 0b0000000001_0001
      ext_io   = 0b0000000001_0010
      ext_clko = 0b0000000001_0011
   }

   ; configuration word2 register, adr0x2008
   pragma fuse_def switch     0b00_0000_0000_0010 {
      on  = 0b00_0000_0000_0010
      off = 0b00_0000_0000_0000
   }

   pragma fuse_def safe_clk   0b00_0000_0000_0001 {
     on  = 0b00_0000_0000_0001
     off = 0b00_0000_0000_0000
}
```

Save the file in `HOME_PJAL\chipdef` folder with the name `c16F8x.jal`.

You must also write the *PIC chip definition file*[12] for the *PIC16F88*:

```
; <c16f88.jal>  this is the name of the following file
include c16f8x

pragma data  0x0020-0x007f, 0x00a0-0x00ef,
             0x120-0x16f, 0x1a0-0x1ef
pragma code  4096
pragma eeprom 0x2100, 256
```

Save the file in `HOME_PJAL\chipdef` folder with the name `c16f88.jal`.

At this moment you are ready to play with your *PIC16F88*. Remember that all SFR's of the *PIC16F88* (or any used bit from any SFR) must be defined before using them![13]

This could be done directly in your project files like in the *Examples section*[14], or by writing a SFR definition file. Keep the register name or bit name identical with those from the PIC

[12] See section 3.1.3 on page 55.
[13] You can test a tool called *inc2jal.exe* developed by STEF MIENTKI[7].
[14] See section 4 on page 71.

datasheet, in this way your library could be used easily by other people. Due to the very large size of SFR definition file, will be presented only a small part of it:

```
; <pjal_16F88._inc.jal> this is the name of the file

-- -----------------------------------------------
-- Special Function Registers in BANK0 of P16F87/88
-- -----------------------------------------------
var volatile byte INDF at {0x00,0x80,0x100,0x180}
var volatile byte TMR0 at {0x01,0x101}

; (all bank0 register definitions must be here)

-- -----------------------------------------------
-- Special Function Registers in BANK1 of P16F87/88
-- -----------------------------------------------
var volatile byte OPTION_REG at 0x81
var volatile byte TRISA      at 0x85

; (all bank1 register definitions must be here)

-- -----------------------------------------------
-- Special Function Registers in BANK2 of P16F87/88
-- -----------------------------------------------
var volatile byte WDTCON    at 0x105
var volatile byte EEDATA    at 0x10C

; (all bank2 register definitions must be here)

-- -----------------------------------------------
-- Special Function Registers in BANK3 of P16F87/88
-- -----------------------------------------------
var volatile byte EECON1   at 0x18C
var volatile byte EECON2   at 0x18D

; (all bank3 register definitions must be here)

-- -----------------------------------------------
-- OPTION_REG associated bits
-- -----------------------------------------------
; this is an example of a complete SFR bit definition
var volatile bit  NOT_RBPU at OPTION_REG : 7
```

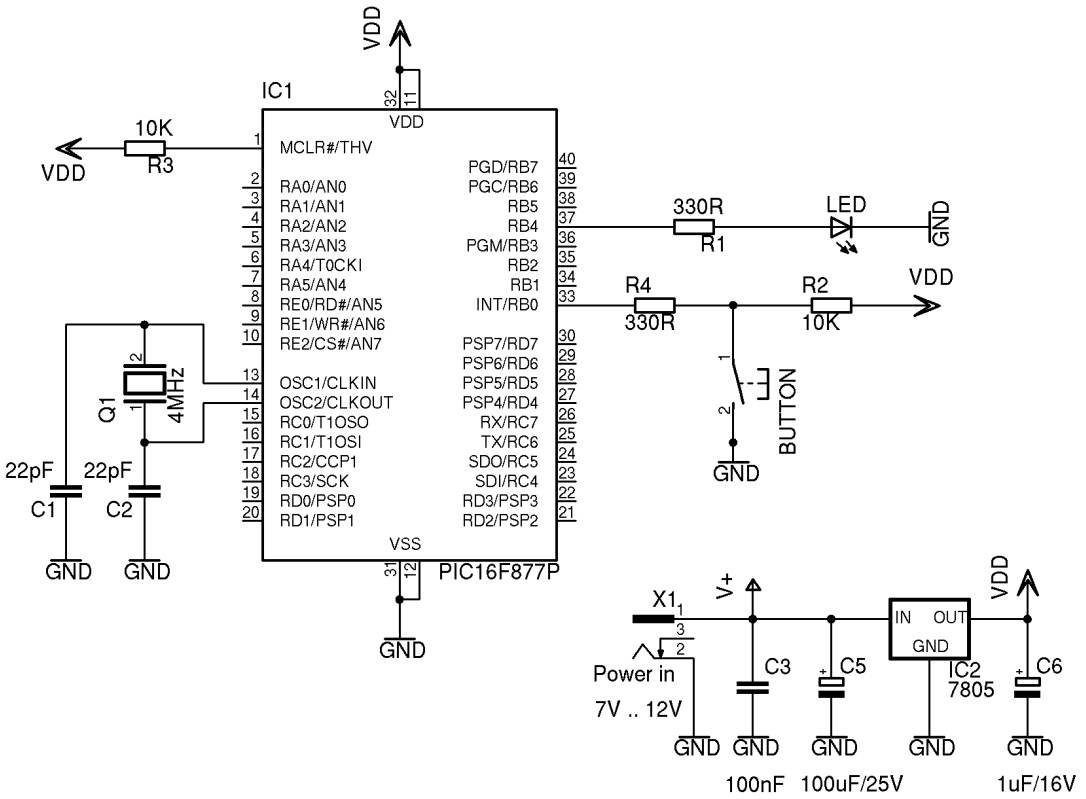
```
var volatile bit  INTEDG   at OPTION_REG : 6
var volatile bit  T0CS     at OPTION_REG : 5
var volatile bit  T0SE     at OPTION_REG : 4
var volatile bit  PSA      at OPTION_REG : 3
var volatile bit  PS2      at OPTION_REG : 2
var volatile bit  PS1      at OPTION_REG : 1
var volatile bit  PS0      at OPTION_REG : 0

; (all other SFR bits definitions must be here)

-- ------------------------------------------------
-- PORTA pins
-- ------------------------------------------------
var volatile bit  pin_a0 at PORTA : 0

; (all port_a bit definitions must be here)

-- ------------------------------------------------
-- PORTB pins
-- ------------------------------------------------
var volatile bit  pin_b0 at PORTB : 0

; (all port_b bit definitions must be here)

-- ------------------------------------------------
-- Port and pin directions
-- ------------------------------------------------
;  only port_a is exemplified but port_b should be also defined
const bit input           = on
const bit output          = off
const byte all_input      = 0b_1111_1111
const byte all_output     = 0b_0000_0000

var volatile byte port_a_direction at _TRISA
var volatile bit pin_a0_direction at _TRISA : 0

; (volatile bit directions for all pins of port_a should be here)

; IO port shadow registers may not be declared as volatile
var byte _port_a_buffer

procedure pin_a0'put( bit in x at _port_a_buffer : 0 ) is
```

```
   porta = _port_a_buffer
end procedure

procedure port_a'put( byte in x ) is
   _port_a_buffer = x
   porta = _port_a_buffer
end procedure

procedure port_a_low'put( byte in x ) is
   _port_a_buffer = ( _port_a_buffer  & 0xF0 ) | ( x & 0x0F )
   porta = _port_a_buffer
end procedure

procedure port_a_high'put( byte in x ) is
   _port_a_buffer = ( _port_a_buffer  & 0x0F ) | ( x << 4 )
   porta = _port_a_buffer
end procedure

function port_a_low'get return byte is
   return porta & 0x0F
end function

function port_a_high'get return byte is
   return (porta >> 4)
end function
```

Save the file in `HOME_PJAL\chipdef` folder with the name `pjal_16F88_inc.jal` in your own library folder or better in your project folder. For a future succesfull compilation, save all your work (including project file, libraries, all PIC definition files, and the **compiler executable file**) every time you're finished a project and it works in the real world.

4 Examples

The examples of this section have been tested in a real PIC. The circuit for all examples is:



A 47nF to 100nF capacitor is recommended between MCLR and ground. this will avoid unvanted resets when noisy loads or power supplies are used.

No PCB layout is given, you are free to build your PCB design.

All example in this section have a number starting each line. These numbers are only here for teaching purposes and should not be in your project files.

4.1 Example 0: Blink a led.

Note: Line numbers are not included in program but used just for explanations !

```
 1  -- This must be in the first line
 2  include c16f877
 3
 4
 5
 6
 7  -- config fuses
 8  pragma target protection off
 9  pragma target debug off
10  pragma target cdp off
11  pragma target lvp off
12  pragma target bor off
13  pragma target powerup on
14  pragma target watchdog off
15  pragma target osc xt
16
17  -- Fosc definition
18  pragma target clock 4_000_000
19
20  -- PORTB and TRISB definitions
21  var volatile byte PORTB at {0x06,0x106}
22  var volatile byte TRISB at {0x86,0x186}
23
24  -- B4 pin definition
25  var volatile bit pin_b4 at PORTB : 4
26
27  -- Led at pin_b4
28  var volatile bit LED is pin_b4
29
30  -- 1 second wait procedure
31  procedure wait_1sec is
32     for 5 loop
33        for 6_500 loop
34           asm nop
35        end loop
36     end loop
37  end procedure
```

```
38
39
40  -- Reset PORTB
41  PORTB = 0
42
43  -- PORTB => all bits output
44  TRISB = 0b_0000_0000
45
46  -- main loop
47  forever loop
48     LED = high  -- LED on
49     wait_1sec
50     LED = low   -- LED off
51     wait_1sec
52  end loop
```

Description

1–2 The first line must be an *include* to a PIC chip definition file[1].

7–15 These configuration fuses must match your specific programmer, etc. Handle with care, a bad configuration will give you a non working PIC.

17–18 Declare the crystal value being used.

20–25 Declare the PIC port to be used. Both PORTx and TRISx are needed. Those lines may be omited if a *register definition file* is included.

27–28 Declare an alias, it's easier to remember.

30–37 A procedure to waste some time. These values will give you a crude approach to one second delay; modify them and see the effect of the LED flashing rate. Use just one instruction `FOR 64_910 LOOP` and see the effect.

40–44 Initialize and configure the port. This initialization part is usually the first lines of the main code.

46–52 Real main code. Here, an endless loop with our magic LED blinking sequence: LED on, wait, LED off, wait. The wait sequence is necessary to see the LED blinking.

[1] See section 3.1.3 on page 55

4.2 Example 1: Scan a button.

Note: Line numbers are not included in program but used just for explanations !

```
 1  -- This must be in the first line
 2  include c16f877
 3
 4
 5
 6
 7  -- config fuses
 8  pragma target protection off
 9  pragma target debug off
10  pragma target cdp off
11  pragma target lvp off
12  pragma target bor off
13  pragma target powerup on
14  pragma target watchdog off
15  pragma target osc xt
16
17  -- Fosc definition
18  pragma target clock 4_000_000
19
20  -- PORTB and TRISB definitions
21  var volatile byte PORTB at {0x06,0x106}
22  var volatile byte TRISB at {0x86,0x186}
23
24  -- B0 pin definition
25  var volatile bit pin_b0 at PORTB : 0
26
27  -- B4 pin definition
28  var volatile bit pin_b4 at PORTB : 4
29
30
31  -- Button at pin_b0
32  var volatile bit Button is pin_b0
33
34  -- Led at pin_b4
35  var volatile bit LED is pin_b4
36
37
```

```
38  -- Reset PORTB
39  PORTB = 0b_0000_0000
40
41  -- PORTB => b7 ..b1 = output, b0 = input
42  TRISB = 0b_0000_0001
43  PORTB = 0b_0000_0001
44
45  -- main loop
46  forever loop
       -- pressed button pulls pin low, see schematic
47     if ! Button then   ; Check if Button pressed
48        LED = on
49     else               ; ... if not pressed
50        LED = off
51     end if
52  end loop
```

Description

1–22 See *Example 0* in section 4.1 1 on page 72.

24–35 Add declarations of both elements being used: the LED and the Button.

38–43 While initializing the port, take care to declare LED pin as *output* and Button pin as *input*.

47 By pressing the Button, the pin will be tied to Ground[2]. In order to detect it with the IF statement we must apply a logical invert to the bit variable. In this way – on pressing button – the logical expression `IF ! Button THEN ...` of the IF statement will be true. Button contact bouncing is not prevented in this program.

47–51 LED will be ON when Button is pressed, and will be OFF when Button is not pressed.

4.3 Example 2: Control the blink of a led.

Note: Line numbers are not included in program but used just for explanations !

```
1  -- This must be in the first line
2  include c16f877
```

[2]See the circuit in section 4 on page 71.

```
 3
 4
 5
 6
 7  -- config fuses
 8  pragma target protection off
 9  pragma target debug off
10  pragma target cdp off
11  pragma target lvp off
12  pragma target bor off
13  pragma target powerup on
14  pragma target watchdog off
15  pragma target osc xt
16
17  -- Fosc definition
18  pragma target clock 4_000_000
19
20
21  -- PORTB and TRISB definitions
22  var volatile byte PORTB at {0x06,0x106}
23  var volatile byte TRISB at {0x86,0x186}
24
25  -- B0 pin definition
26  var volatile bit pin_b0 at PORTB : 0
27
28  -- B4 pin definition
29  var volatile bit pin_b4 at PORTB : 4
30
31
32  -- Button at pin_b0
33  var volatile bit Button is pin_b0
34
35  -- Led at pin_b4
36  var volatile bit LED is pin_b4
37
38  -- 1 second wait procedure
39  procedure wait_1sec is
40     for 5 loop
41        for 6_500 loop
42           asm nop
43        end loop
44     end loop
```

```
45  end procedure
46
47  procedure delay_miliseconds is
48     for 1000 loop
49        asm nop
50     end loop
51  end procedure
52
53  -- Reset PORTB
54  PORTB = 0b_0000_0000
55
56  -- PORTB => output
57  TRISB = 0b_0000_0001
58  PORTB = 0b_0000_0001
59
60  -- main loop
61  forever loop
62     if ! Button then   ; Check if Button pressed
63        delay_milisecons
64        if ! Button then
65           ; Check again if Button pressed
66           LED = on
67           wait_1sec
68           LED = off
69           wait_1sec
70         end if
71     end if
72  end loop
```

Description

1–36 See *Example 1* in section 4.2 1 on page 74.

38–45 See *Example 0* in section 4.1 on page 72.

53–58 See *Example 1* in section 4.2 1 on page 74.

62 See *Example 1* in section 4.2 1 on page 74.

62–71 In this example the LED will blink *only* when Button is pressed longer than a few miliseconds.

4.4 Example 3: Adding a hardware timer.

Note: Line numbers are not included in program but used just for explanations !

```
 1  -- This must be in first line
 2  include c16f877
 3
 4
 5
 6
 7  -- config fuses
 8  pragma target protection off
 9  pragma target debug off
10  pragma target cdp off
11  pragma target lvp off
12  pragma target bor off
13  pragma target powerup on
14  pragma target watchdog off
15  pragma target osc xt
16
17  -- Fosc definition
18  pragma target clock 4_000_000
19
20
21  -- PORTB and TRISB definitions
22  var volatile byte PORTB at {0x06,0x106}
23  var volatile byte TRISB at {0x86,0x186}
24
25  -- B0 pin definition
26  var volatile bit pin_b0 at PORTB : 0
27
28  -- B4 pin definition
29  var volatile bit pin_b4 at PORTB : 4
30
31
32  -- Button at pin_b0
33  var volatile bit Button is pin_b0
34
35  -- Led at pin_b4
36  var volatile bit LED is pin_b4
37
```

```
38
39  -- 1 millisecond wait procedure
40  -- TMR0_delay=(256-InitTMR0)*4*prescaler/Fosc
41  -- TMR0_delay=(256-6)*4*4/4_000_000= 1 msec.
42  --
43  -- InitTMR0 = 6
44  -- Prescaler = 1:4
45  -- Fosc = 4_000_000
46  --
47  -- Delay = 0.001 secs
48
49
50  -- Init TMR0, free run mode, int osc, prescaler 1:4
51  var volatile byte TMR0 at {0x01,0x101}
52  var volatile byte OPTION_REG at {0x81,0x181}
53  OPTION_REG = 0b_1000_0001
54
55  -- Disable interrupts, reset TMR0 flag
56  var volatile byte INTCON at {0x0B,0x8B,0x10B,0x18B}
57  var volatile bit T0if at INTCON : 2
58  INTCON = 0
59
60  const byte InitTMR0 = 6
61
62  procedure wait_1sec is
63     for 1_000 loop
64        -- Wait for TMR0 1 msec.
65        while ( ! T0if ) loop
66        end loop
67        -- Reset TMR0IF
68        T0if = low
69        -- Add InitTMR0
70        TMR0 = TMR0 + InitTMR0
71     end loop
72  end procedure
73
74
75  -- Reset PORTB
76  PORTB = 0b_0000_0000
77
78  -- PORTB => B0 input, B1..B7 output
79  TRISB = 0b_0000_0001
```

```
80  PORTB = 0b_0000_0001
81
82
83  -- main loop
84  forever loop
85     if ! Button then ; Check if Button is
86                      ; permanently pressed
87        LED = on
88        wait_1sec
89        LED = off
90        wait_1sec
91     end if
92  end loop
```

Description

1–36 See *Example 1* in section 4.2 1 on page 74.

39–47 Inline comments with a brief description how to set TMR0. Take your PIC chip datasheets and read the section entitled *TIMER 0*. The goal in this example is to get a TMR0 overflow each millisecond. Using a 4MHz crystal, it's necessary a prescaler of 1:4 and init TMR0 with a constant value each time it overflows.

50–58 Declare and initialize the SFRs related with TMR0. See your PIC chip datasheets, here TMR0 will work in *free running mode*.

62–72 At this point TMR0 overflows each millisecond and will set a bit called T0IF. The WHILE statement will stop program until T0IF is set (TMR0 overflow), so we *must* reset this bit and load TMR0 with the init constant value. Doing these steps 1000 times will give us one second delay.

75–80 See *Example 1* in section 4.2 1 on page 74.

83–92 In this example the LED will blink *only* when Button is kept pressed.

4.5 Example 4: Using hardware interrupts.

Note: Line numbers are not included in program but used just for explanations !

```
1  -- This must be in the first line
2  include c16f877
```

```
 3
 4
 5
 6
 7  -- config fuses
 8  pragma target protection off
 9  pragma target debug off
10  pragma target cdp off
11  pragma target lvp off
12  pragma target bor off
13  pragma target powerup on
14  pragma target watchdog off
15  pragma target osc xt
16
17  -- Fosc definition
18  pragma target clock 4_000_000
19
20  -- PORTB and TRISB definitions
21  var volatile byte PORTB at {0x06,0x106}
22  var volatile byte TRISB at {0x86,0x186}
23
24  -- B0 pin definition
25  var volatile bit pin_b0 at PORTB : 0
26
27  -- B4 pin definition
28  var volatile bit pin_b4 at PORTB : 4
29
30
31  -- Button at pin_b0
32  var volatile bit Button is pin_b0
33
34  -- Led at pin_b4
35  var volatile bit LED is pin_b4
36
37
38  -- 1 millisecond delay
39  -- TMR0_delay=(256-InitTMR0)*4*prescaler/Fosc
40  -- TMR0_delay=(256-6)*4*4/4_000_000= 1 msec.
41  --
42  -- InitTMR0 = 6
43  -- Prescaler = 1:4
44  -- Fosc = 4_000_000
```

```
45  --
46  -- Delay = 0.001 secs
47
48  -- RB0INT falling edge, Init TMR0, free run mode,
49  -- int osc, prescaler 1:4
50  var volatile byte TMR0 at {0x01,0x101}
51  var volatile byte OPTION_REG at {0x81,0x181}
52  OPTION_REG = 0b_1000_0001
53
54  -- Enable TMR0 interrupt, RB0INT interrupt, reset flags
55  var volatile byte INTCON at {0x0B,0x8B,0x10B,0x18B}
56  var volatile bit T0if at INTCON : 2
57  var volatile bit INTf at INTCON : 1
58  var volatile bit INTE at INTCON : 4
59  var volatile bit T0IE at INTCON : 5
60  INTCON = 0B_1011_0000
61  const byte InitTMR0 = 6
62  var volatile bit Enable_Button is INTE
63  var volatile bit Enable_Timmer is T0IE
64
65  Enable_Timmer = off
66  Enable_Button = on
67
68  -- declare vars
69  var word milisec_count
70  var bit Flag_tmr0 = false, Flag_rb0int = false
71
72  -- TMR0 interrupt
73  procedure TMR0_ISR is
74  pragma interrupt
75     if T0if then
76        -- Reset TMR0IF
77        T0if = low
78        -- Reset InitTMR0
79        TMR0 = InitTMR0
80        -- add one count
81        milisec_count = milisec_count + 1
82        -- Check count 1_000
83        if milisec_count == 1_000 then
84           -- if 1000 msecs. => Activate flag
85           Flag_tmr0 = true
86           -- reset counter
```

```
 87           milisec_count = 0
 88        end if
 89     end if
 90  end procedure
 91
 92  -- RB0INT interrupt
 93  procedure RB0INT_ISR is
 94  pragma interrupt
 95     if INTf then
 96        -- Reset TMR0IF
 97        INTf = low
 98        -- Activate flag
 99        Flag_rb0int = true
100        -- reset counter
101        milisec_count = 0
102        TMR0 = 6
103        -- Enable timmer
104        Enable_Timmer = on
105     end if
106  end procedure
107
108
109  -- Reset PORTB
110  PORTB = 0b_0000_0000
111
112  -- PORTB => B0 input, B1..B7 output
113  TRISB = 0b_0000_0001
114  PORTB = 0b_0000_0001
115
116
117  -- main loop
118  forever loop
119     if Flag_rb0int then   ; Check if Button pressed
120        -- Disable Button interrupt
121        Enable_Button = low
122        -- Turn on LED
123        LED = on
124        -- Wait for 1 sec event
125        while ( ! Flag_tmr0 ) loop
126        end loop
127        -- Clear flag
128        Flag_tmr0 = low
```

```
129         -- Turn off LED
130         LED = off
131         -- Wait for 1 sec event
132         while ( ! Flag_tmr0 ) loop
133         end loop
134         -- Clear flag
135         Flag_tmr0 = low
136         -- Enable Button interrupt
137         Enable_Button = High
138         -- Disable timmer interrupt
139         Enable_Timmer = low
140         -- Clear flags
141         Flag_rb0int = low
142         Flag_tmr0 = low
143      end if
144   end loop
```

Description

1–35 See *Example 1* in section 4.2 1 on page 74.

38–46 See *Example 3* in section 4.4 1 on page 78.

49–52 Declare and initialize the SFRs related with TMR0. See your PIC chip datasheets, here TMR0 will work in *free running mode*. Set also RB0INT edge detection to *falling edge*.

54–60 Declare and configure TMR0 and RB0INT interrupts

62–66 Declare some alias, it's easier to remember.

68–70 Declare some variables to be used globally. `Flag_tmr0` and `Flag_rb0in` will be used by main program to know about interrupt events.

72–90 TMR0 interrupt procedure.

75 Check if is exactly TMR0 interrupt.

76–79 Reset flag and init TMR0 again.

80–81 Add one count to our *1000 milliseconds* count.

82–88 On reaching the 1000 milliseconds count, set `Flag_tmr0` and reset internal count.

92–106 RB0INT interrupt procedure.

95 Check if is exactly RB0INT interrupt.

96–97 Reset flag RB0INT.

98–105 Set `Flag_rb0in`, enable TMR0 (will be disabled anywhere) and reset TMR0 count. In this way TMR0 will start counting only when Button is pressed.

109–114 See *Example 1* in section 4.2 on page 74.

117-144 Main code. In this example the LED will blink only once each time Button is pressed.

119 Scan Button testing `Flag_rb0in` bit. The interrupt procedure will do all hard job.

120–123 Disable future Button interrupt events.

122–135 The *magic sequence* to blink a LED.

124–128 Turn on LED and wait for one second by testing `Flag_tmr0`. Clear flag for next use.

129–135 Turn off LED and wait for one second by testing `Flag_tmr0`. Clear flag for next use.

136–142 Enable Button interrupt events again, disable TMR0 interrupt events (work already done in this loop) and clear both flags.

5 Glossary

ACCESSOR An accessor method is a method that is usually small, simple and provides the means for the state of an object to be accessed from other parts of a program. An accessor method that changes the state of an object is often called an update method or, sometimes, mutator method. Objects that provide such methods are considered mutable objects. See Wikipedia [5], keyword: Accessor.

ANALOG DEVICE An analog device is a component of a electronic circuit that change its properties continuously in both time and amplitude. It differs from digital devices in that small fluctuations in the signal are meaningful in that they are continuously variable rather than digitally quantised.

ATOMIC A single operation, with single as in *non interuptable*. It has to finish before anything else can be done. Which implies that a *singe operation* might take more than one machine instruction but they all must finisch before any interupt can interfere with the processor. On most processors *atomic* is equivalent to one *instruction*.

BANK see MEMORY BANK.

BINARY CONSTANT Begins with `"0b"` and continues until the first character not in the set {`"_"`, `"0"`, `"1"`}. It's fully evaluated at compile time.

BIT or *binary digit.* Is the smallest unit of data and has a boolean value.

BITMASK also MASK. Extracts the status of certain bits in a binary string or number.

BITWISE OPERATOR Operates on individual BITs of one or two operands. See Wikipedia [5], keyword: Bitwise.

BITWISE COMPLEMENT An operator that changes all BITs of an operand from 1 to 0 or vice versa. See Wikipedia [5], keyword: One's_complement.

BITWISE AND An operator that takes two bit patterns of equal length, and produces another one of the same length by matching up corresponding bits (the first of each; the second of each; and so on) and performing the logical AND operation on each pair of corresponding bits. In each pair, the result is 1 if the first bit is 1 AND the second bit is 1. Otherwise, the result is zero. See Wikipedia [5], keyword: Bitwise.

BITWISE OR An operator that takes two bit patterns of equal length, and produces another one of the same length by matching up corresponding bits (the first of each; the second of each; and so on) and performing the logical OR operation on each pair of corresponding bits. In each pair, the result is 1 if the first bit is 1 OR the second bit is 1. Otherwise, the result is zero. See Wikipedia [5], keyword: Bitwise.

BITWISE XOR An operator that takes two bit patterns of equal length, and produces another one of the same length by matching up corresponding bits (the first of each; the second of each; and so on) and performing the logical OR operation on each pair of corresponding bits. In each pair, the result is 1 if the two bits are different, and 0 if they are the same. See Wikipedia [5], keyword: Bitwise.

BOOLEAN Boolean logic is a form of algebra in which all values are reduced to either TRUE or FALSE. In *JAL 2.0* this means TRUE or FALSE, also ON or OFF are valid and either 1 and 0. See Wikipedia [5], keyword: Boolean.

CONTACT BOUNCE Contact bounce is a common problem with mechanical switches and relays. When the contacts strike together, their momentum and elasticity act together to cause bounce. The result is a rapidly pulsed electrical current instead of a clean transition from zero to full current. If the switch voltage is fed directly to the input of a microprocessor, then the software might become confused by the rapid sequence of high and low logic levels when it is expecting only a single, stable transition between "on" and "off". See Wikipedia [5], keyword: Switch.

COMPILER DIRECTIVE Data embedded in source code to tell the compiler some intention about compilation. See Wikipedia [5], keyword: Compiler_directive.

CO-OPERATIVE MULTITASKING (or non-preemptive multitasking) is a form of multitasking in which multiple tasks execute by voluntarily ceding control to other tasks at programmer-defined points within each task. See Wikipedia [5], keyword: Co-operative_multitasking.

DECIMAL CONSTANT Begins with a digit, and continues until the first character not in the set {`"_"`, digit}. It's fully evaluated at compile time.

DECLARATION Specifies a variable's dimensions, identifier, type, and other aspects.

DIGIT A character in the set {"0"–"9"}.

ENDIANNESS The two main types of endianness are known as big-endian and little-endian. In *big-endian*, the most significant byte (MSB) is stored at the memory location with the lowest address. In *little-endian*, the least significant byte (LSB) is stored at the memory location with the lowest address. pJAL and PICs uses *little-endian* memory management. See Wikipedia [5], keyword: Endianness.

EXPRESSION Anything that evaluates to a value, for example x + 1.

IDENTIFIER Begins with a member of the set {"_", "a"–"z", "A"–"Z"} and continues until the first character *NOT* in the set {"_", "a"–"z", "A"–"Z", digit}.

INTERRUPT is an asynchronous signal from hardware (or software) indicating the need for attention. Originated as a way to avoid wasting the processors valuable time in polling loops, waiting for external events. Instead, an interrupt signals the processor when an event occurs, allowing the processor to process other work while the event is pending. See Wikipedia [5], keyword: Interrupt.

HEXADECIMAL CONSTANT Begins with "0x" and continues until the first character not in the set {"_", "0"–"9", "a"–"f", "A"–"F"}. It's fully evaluated at compile time.

LOGICAL EXPRESSION The result is 0 if the expression evaluation is zero, and 1 if the expression evaluation is anything other than 0.

LOGICAL NOT An operator that changes the boolean state from TRUE to FALSE or vice versa.

LSB It is the byte in that position of a multi-byte number which has the least potential value. If it's written in lowercase, means the lowest BIT. See Wikipedia [5], keyword: Least_significant_byte.

MEMORY BANK PIC architecture typically has more memory registers than can be addressed in a single byte address. A special SFR register is utilized to switch to another bank of memory where the base addresses repeat. Check the specific PIC datasheet to determine the number of banks and their size.

MODULO The modulo operation finds the remainder of division.

MSB It is the byte in that position of a multi-byte number which has the greatest potential value. If it's written in lowercase, means the greatest BIT. See Wikipedia [5], keyword: Most_significant_byte.

MULTITASKING is a method by which multiple tasks, also known as processes, share common processing resources such as a CPU. See Wikipedia [5], keyword: Computer_multitasking.

NIBBLE Half of a an 8 bit byte, a group of 4 bits. Corresponding *JAL 2.0 type* is BIT*4, eg: you can send data to a HD44780 LCD in nibble (4 bit) mode.

OCTAL CONSTANT Begins with `"0q"` and continues until the first character not in the set {`"_"`, `"0"`–`"7"`}. It's fully evaluated at compile time.

OPERATOR The most basic mathematical or logical functions usually represented by a single character eg: + - *

OPERAND One of the inputs (arguments) of an operator.

PRAGMA (short for "*pragmatic information*"), see COMPILER DIRECTIVE.

STRING CONSTANT Begins with `'` and continues until the next `'`. Also, begins with `"` and continues until the next `"`. It's fully evaluated at compile time.

TOKENS *JAL 2.0* syntax is based on tokens. In programming languages, a single element of a programming language. In *JAL 2.0* can be an identifier, constant, operator, or any non-space character. See Wikipedia [5], keyword: Token.

TRINARY OPERATOR An operator which three operands are associated with the operator. Example: in C programming language the `?` operator, `c?a:b`.

UNARY OPERATOR Also MONADIC operator. An operator which only takes one operand (argument), eg: -1 (a negative value).

VAR Variable.

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