The SpecC Language Reference Manual

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Abstract

This Language Reference Manual defines the syntax and the semantics of the SpecC language.

The SpecC language is an extension of the ANSI-C programming language. Since ANSI-C is already well-documented, this report only describes the special constructs that were added for SpecC.

For each SpecC construct, the syntax, the purpose and the semantics are documented and an example is given for easy explanation. Also, the full SpecC grammar is included using a formal notation in lex and yacc style.

Contents

1 Introduction

The SpecC language, as introduced in [3, 4, 5], is a modeling language for the specification and design of embedded systems at system level. For more information about the design methodology behind the SpecC language, please refer to [6, 7]. This report contains the SpecC Language Reference Manual which contains the definition of the syntax and the semantics of the language.

The SpecC language is an extension of the C programming language and is based on the ANSI-C standard [1]. As a true superset, SpecC covers the complete set of ANSI-C constructs. Since ANSI-C is already well-documented in the literature, this report assumes that the reader is familiar with the syntax, semantics and concepts of the ANSI-C language. The report only describes the keywords and constructs of the SpecC language that were added and are not found in ANSI-C. Section 2 defines these special data types, statements and constructs.

As an official reference, the appendix contains the full SpecC grammar formally defined using the `lex` and `yacc` syntax notation.

2 Syntax and Semantics

This section defines the types, statements, expressions and constructs of the SpecC language that are not part of ANSI-C.

2.1 Boolean Type

Purpose: Explicit support of the Boolean data type

Synopsis:

```
basic_type_name:                    /* BasicType */
        ...
        | bool

constant:                           /* Constant */
        ...
        | false
        | true
```

Example:

```
bool f(bool b1, int a)
{
    bool b2;

    if (b1 == true)
        { b2 = b1 || (a > 0);
        }
    else
        { b2 = !b1;
        }
    return(b2);
}
```

Semantics:

A Boolean value, of type **bool**, can have only one of two values: **true** or **false**. It can be used to express the result of logical operations (e. g. <, >, ==, etc.). If converted (implicitly or explicitly) to an integer type, **true** becomes 1 and **false** becomes 0.

2.2 Bitvector Type

Purpose: Explicit support for bitvectors of arbitrary length

Synopsis:

```
bindigit        [01]
binary          {bindigit}+
bitvector       {binary}("b"|"B")
bitvector_u     {binary}("ub"|"bu"|"uB"|"Bu"|"Ub"|"bU"|"UB"|"BU")

basic_type_name:                    /* BasicType */
        ...
        | bit '[' constant_expression ':' constant_expression ']'

constant:                           /* Constant */
        ...
        | bitvector
        | bitvector_u

postfix_expression :                /* Expression */
        ...
        | postfix_expression '[' comma_expression ']'
        | postfix_expression '[' constant_expression ':' constant_expression ']'

concat_expression:                  /* Expression */
        cast_expression
        | concat_expression '@' cast_expression
```

Example:

```
typedef bit[3:0]          nibble_type;
nibble_type               a;
unsigned bit[15:0]        c;

void f(nibble_type b, bit[16:1] d)
{
   a = 1101B;                        /* bitvector assignment */
   c = 1110001111100011ub;
   c[7:4] = a;                       /* bitslice assignment */

   b = c[2:5];                       /* bitvector slicing */
   c[0] = c[16];                     /* single bit access */
   d = a @ b @ c[0:15];              /* bitvector concatenation */
   b += 42 + a * 12;                 /* arithmetic operations */
   d = ~(b | 10101010B);             /* logic operations */
```

```
16 }
```

Semantics:

A bitvector represents an integral data type of arbitrary precision (length). A bitvector can be **signed** or **unsigned**. It can be used as any other integral type in expressions (for example, type **int** is equivalent to type **bit**$[sizeof(\mathbf{int}) * 8 - 1 : 0]$). Implicit promotion to (**unsigned**) **int**, **long**, **long long**, **double**, or **long double** is performed when necessary. Automatic conversion (signed/unsigned extension or truncation) is supported as with any other integral type. No explicit type casting is necessary.

A bitvector can be thought of as a parameterized type whose bounds are defined with the name of the type. The left and right bounds of a bitvector must be constant expressions that will be evaluated at compile time. Therefore, the length of any bitvector expression is always known at compile time (this is important for synthesis!).

Bitvector constants are noted as a sequence of zeros and ones directly followed with a suffix **u** or **ub** indicating the bitvector type (see the synopsis and example above).

In addition to all standard C operations, a concatenation operation, noted as @, and a slicing operation, noted as $[lb : rb]$, are supported (see lines 9 and 11 in the example above). Both operations can be applied to bitvectors as well as to any other integral type (which will be treated as bitvector of suitable length).

Also, a bit-access operation, noted as $[b]$ (same as the array access operator), is provided as a shorthand for accessing a single bit ($[b : b]$) of a bitvector. The result type of this operation is **unsigned bit**$[0 : 0]$.

Please note that the slicing operation requires the left and right bounds to be constant expressions which can be evaluated at compile time. This restriction does not apply to the single bit access.

2.3 Event Type

Purpose: Events serve as a mechanism for synchronization and exception handling

Synopsis:

```
basic_type_name:                     /* BasicType */
        ...
        | event

wait_statement:                      /* Statement */
        wait paren_event_list ';'

notify_statement:                    /* Statement */
        notify paren_event_list ';'
        | notifyone paren_event_list ';'
```

Example:

```
int     d;
event   e;

void send(int x)
{
   d = x;
   notify e;
}

int receive(void)
{
   wait e;
   return(d);
}
```

Semantics:

The type **event** is a special type that enables SpecC to support exception handling and synchronization of concurrent executing behaviors.

An event does *not* have a value. Therefore, an event must not be used in any expression. Events can only be used with the **wait** and **notify** statements (see the example above and Section 2.15), or with the **try-trap-interrupt** construct described in Section 2.14.

2.4 Time Type

Purpose: Simulation time with support of timed (hardware) and untimed behavior (software)

Synopsis:

```
primary_expression:                 /* Expression */
        ...
        | delta

waitfor_statement:                  /* Statement */
        waitfor time ';'

time:                               /* Expression */
        constant_expression
```

Example:

```
extern void      f(void);
const long int   CycleTime = 15;  /* ns */

void Timed(void)
{
   while(true)
      { f();
        waitfor(CycleTime);
      }
}

void Untimed(void)
{
   while(true)
      { f();
        waitfor(delta);
      }
}
```

Semantics:

The time type represents the type of the simulation time. Time is not an explicit type. It is an implementation dependent integral type (for example **unsigned long long**).

The time type is used only with the **waitfor** statement and with the **do-timing** construct (see Section 2.16).

For untimed behavior (behavior with unknown timing, e. g. software) the **delta** time variable is provided. The **delta** variable is of type time and is measured in implementation and simulator dependent units (e. g. nanoseconds).

During simulation, **delta** evaluates to the execution time of the current behavior on the host machine. The simulation run-time library keeps track of the real-time when executing a behavior. **delta** is the time elapsed since the last scheduler entry, in other words, the time spent for execution since the last **wait**, **waitfor**, **notify**, or **delta** statement.

2.5 Behavior Class

Purpose: Object for specification of behavior; container for computation

Synopsis:

```
behavior_declaration:               /* void */
        behavior_specifier port_list_opt implements_interface_opt ';'

behavior_definition:                /* void */
        behavior_specifier port_list_opt implements_interface_opt
                '{' internal_definition_list_opt '}' ';'

behavior_specifier:                 /* Declarator */
        behavior identifier

implements_interface_opt:           /* SymbolPtrList */
        /* nothing */
        | implements interface_list

interface_list:                     /* SymbolPtrList */
        interface_name
        | interface_list ',' interface_name

primary_expression:                 /* Expression */
        ...
        | this
```

Example:

```
behavior B (in int p1, out int p2)
{
   int  a, b;

   int f(int x)
      {
         return(x * x);
      }

   void main(void)
      {
         a = p1;          /* read data from input port */
         b = f(a);        /* compute */
         p2 = b;          /* output to output port */
      }
};
```

Semantics:

In SpecC, the functionality of a system is described by a hierarchical network of behaviors. A **behavior** is a class that consists of an optional set of ports and an optional set of implemented interfaces. A behaviors body consists of an optional set of instantiations, an optional set of local variables and methods, and a mandatory main method.

Through its ports, a behavior can communicate with other behaviors. This is described in detail in Section 2.8.

Although this is rarely used, a behavior may implement a list of interfaces, as described with the channel construct in Section 2.6. For behaviors, implemented interfaces declare the (call-back) methods which can be called from outside. In this case, a behavior can refer to itself with the **this** keyword (see Section 2.7). Otherwise, all methods in a behavior are private, except the `main` method.

A behavior is called a composite behavior if it contains instantiations of other behaviors (as described in Section 2.9). Otherwise, it is called a leaf behavior.

Local variables and methods, as a, b, and f in the example above, can be used to conveniently program the functionality of a behavior. The `main` method of a behavior, usually the only method accessable from the outside, is called whenever an instantiated behavior is executed. Also, the completion of the `main` method determines the completion of the execution of the behavior.

A behavior is compatible with another behavior if the number and the types of the behavior ports (and the implemented interfaces) match. Compatibility of behaviors is important for reuse of IP and "plug-and-play". Please note that a behavior declaration, which is a behavior without a body, contains all information about the behavior that is necessary to determine its use and its compatibility. This is of critical importance in order to allow IP behaviors whose body is unknown.

A behavior definition (a behavior with body) requires that all interfaces implemented by the behavior are already defined with a body.

The example above shows a simple leaf behavior. For typical composite behaviors, please refer to Sections 2.10 to 2.14.

Every SpecC program starts with the execution of the `main` method of the `Main` behavior. Therefore, the behavior `Main` usually is a composite behavior containing the testbench for a design as well as the instantiation of the actual design specification.

Please note that, although `main` and `Main` are recognized by the SpecC compiler as names denoting the start of the program and start of a behavior, these names are not keywords of the SpecC language.

2.6 Channel Class

Purpose: Object for specification of protocols; container for communication

Synopsis:

```
channel_declaration :                /* void */
        channel_specifier  port_list_opt  implements_interface_opt  ';'

channel_definition :                 /* void */
        channel_specifier  port_list_opt  implements_interface_opt
                '{'  internal_definition_list_opt  '}' ';'

channel_specifier :                  /* Declarator */
        channel  identifier

implements_interface_opt :           /* SymbolPtrList */
        /* nothing */
        | implements  interface_list

interface_list :                     /* SymbolPtrList */
        interface_name
        | interface_list  ','  interface_name
```

Example:

```
interface I;

channel C (void) implements I
{
   int  data;

   void send(int x)
      {
         data = x;
      }

   int receive(void)
      {
         return(data);
      }
};
```

Semantics:

Communication between behaviors can be encapsulated in channels. A **channel** declaration is a class that consists of an optional set of ports and an optional set of implemented interfaces specified after the **implements** keyword. As a definition, the channels body consists of an optional list of instantiations and an optional set of local variables and methods.

A channel can include a list of ports through which it can communicate with other channels or behaviors (although channel ports are rarely used). Ports are described in detail in Section 2.8.

A channel is called a hierarchical channel if it contains instantiations of other channels (as described in Section 2.9). A channel is called a wrapper if it instantiates behaviors.

In general, variables and methods defined in a channel cannot be accessed from the outside (in contrast to members of structures). However, by using interfaces (described in Section 2.7), a subset of the internal methods can be made public. The **implements** keyword declares the list of interfaces that are implemented by the channel. All the methods of the implemented interfaces must be defined inside the channel. Therefore, a channel definition (a channel with body) requires that all implemented interfaces are definitions (have a body).

A channel is compatible with another channel if the number and the types of the channel ports, and the list of the implemented interfaces match.

The example above shows a simple channel providing a simple communication protocol via an encapsulated integer variable.

2.7 Interface Class

Purpose: Link between behaviors and channels; support for reuse of IP and ”plug-and-play”

Synopsis:

```
interface_declaration:              /* void */
        interface_specifier ';'

interface_definition:               /* void */
        interface_specifier '{' internal_declaration_list_opt '}' ';'

interface_specifier:                /* Declarator */
        interface identifier

internal_declaration_list_opt:      /* void */
        /* nothing */
        | internal_declaration
        | internal_declaration_list internal_declaration

internal_declaration:               /* void */
        declaration
        | note_definition
```

Example:

```
interface I
{
   void send(int x);
   int receive(void);
};

interface I4B
{
   int get_word(void);
   void put_word(int d);
};

interface I4C
{
   void send_block(I4B b);
   void receive_block(I4B b);
};
```

Semantics:

Interfaces can be used to connect behaviors with channels in a way so that both, the behaviors and the channels, are easily interchangable with compatible components ("plug-and-play"). An **interface** is a class that consists of a set of method declarations. The method definitions for these declarations are supplied by a channel (or behavior) that **implements** the interface.

A typical use of an interface is a behavior with a port of interface type. Via such an interface port, a behavior can call the communication methods declared in that interface. The actual channel performing these methods is determined by the mapping of the interface port.

For each interface, multiple channels can provide an implementation of the declared communication methods and each of these channels then can be connected to the behavior with the interface port when the behavior is instantiated (see Section 2.9).

The example above shows the **interface** I which declares the *send* and *receive* methods for the channel C in the example from Section 2.6.

The interfaces $I4C$ and $I4B$ in the example can be used to define a communication scheme involving call-backs. Assuming, there is a behavior B implementing interface $I4B$ and a channel C implementing interface $I4C$, the communication protocol is initiated by the behavior B with a call to *send_block* or *receive_block*, where the behavior B supplies itself as an argument (with the keyword **this**). These methods, implemented in the channel C, can then call-back the methods *get_word* and *put_word* in order to get or store the data word by word.

2.8 Ports

Purpose: Specification of connectors of behaviors and channels

Synopsis:

```
port_list_opt:                    /* ParameterList */
        /* nothing */
        | '(' ')'
        | '(' port_list ')'

port_list:                        /* ParameterList */
        port_declaration
        | port_list ',' port_declaration

port_declaration:                 /* Parameter */
        port_direction parameter_declaration
        | interface_parameter

port_direction:                   /* Direction */
        /* nothing */
        | in
        | out
        | inout

interface_parameter:              /* Parameter */
        interface_name
        | interface_name identifier
```

Example:

```
interface I;

behavior B1 (in int p1, out int p2, in event clk);

behavior B2 (I i, inout event clk);

channel C (inout bool f) implements I;
```

Semantics:

Behavior and channel classes can have a list of ports through which they communicate. These ports are defined with the definition of the behavior or channel they are attached to (exactly like function parameters are defined with the function definition).

A port can be one of two types: standard or interface type. A standard type port can be of any SpecC type, but includes the ports direction as an additional type modifier. A port direction can be **in**, **out**, or **inout**, and is handled as an access restriction to that port. An **in** port allows only read-access from inside the class (write-access from the outside), an **out** port only allows write-access from the inside (read-access from the outside). An **inout** port can be accessed bi-directionally. As a shortcut, a port without any direction modifier is considered an **inout** port.

On the other hand, an interface type port enables access to the methods of that interface class. Via such a port, a behavior or a channel can call any of the public methods of the connected class.

2.9 Class Instantiation

Purpose: Specification of behavioral hierarchy and connectivity among behaviors and channels

Synopsis:

```
instance_declaring_list:          /* DeclarationSpec */
        behavior_or_channel instance_declarator
        | instance_declaring_list ',' instance_declarator

instance_declarator:              /* Declarator */
        identifier port_mapping_opt

behavior_or_channel:              /* DeclarationSpec */
        behavior_name
        | channel_name

port_mapping_opt:                 /* PortMapList */
        /* nothing */
        | '(' ')'
        | '(' port_mapping_list ')'

port_mapping_list:                /* PortMapList */
        port_mapping
        | port_mapping_list ',' port_mapping

port_mapping:                     /* BitSliceList */
        bit_slice
        | port_mapping '&' bit_slice

bit_slice:                        /* BitSlice */
        identifier
        | identifier '[' constant_expression ':' constant_expression ']'
        | identifier '[' constant_expression ']'
```

Example:

```
interface I;
channel   C  (inout bool f) implements I;
behavior  B1 (in int p1, out bit[7:0] p2, in event clk);
behavior  B2 (I i, out event clk);

behavior B (bit[7:0] bus1, bit[15:0] bus2)
{
   bool         b;
   int          i;
```

```
10    event          e;
11
12    C     c(b);             /* instantiate c as channel C */
13    B1    b1(i, bus1, e),   /* instantiate b1 and b3 as behavior B1 */
14          b3(i, bus2[15:8], e);
15    B2    b2(c, e);         /* instantiate b2 as behavior B2 */
16 };
```

Semantics:

SpecC supports behavioral hierarchy by allowing (sub-) behaviors and (sub-) channels to be instantiated as components inside compound behaviors and channels. The instantiation of behaviors and channels also defines the connectivity of the instantiated components.

An instantiation defines its connections by use of a port mapping list. Each port of the instantiated class must be mapped onto a corresponding variable or port of suitable type. A port must match the type of the mapped variable or port, just as the types or arguments to a function call must match the types of the function parameters. Also, the port directions must be compatible. As a rule, for each connection, there can be at most one driver. For example, two **out** ports cannot be connected, whereas two **in** ports can.

As a special case, a port of bitvector type can be connected to a list of concatenated bitslices. For example, a port of type **bit**$[15:0]$ can be mapped onto two adjacent busses $a[7:0]@b[0:7]$.

The example above contains four class instantiations. In line 12, a channel c is instantiated as type channel C. Its only port of type **bool** is mapped to the Boolean variable b.

Lines 13 and 14 instantiate two behaviors $b1$ and $b3$ (of type behavior $B1$) which are both connected to integer i and event e. The second port of $b1$ is connected to $bus1$ (the first port of B), whereas the second port of $b3$ is mapped to the higher bits of $bus2$.

In line 15, $b2$ is instantiated as a $B2$ type behavior. Its ports are mapped to the channel c (instantiated in line 12) and event e.

2.10 Sequential Execution

Purpose: Specification of sequential control flow

Synopsis:

```
statement:                                /* Statement */
        labeled_statement
        | compound_statement
        | expression_statement
        | selection_statement
        | iteration_statement
        | jump_statement
        | spec_c_statement

spec_c_statement:                         /* Statement */
        concurrent_statement
        | fsm_statement
        | exception_statement
        | timing_statement
        | wait_statement
        | waitfor_statement
        | notify_statement
```

Example:

```
behavior B;

behavior B_seq(void)
{
   B     b1, b2, b3;

   void main(void)
   {
       b1.main();
       b2.main();
       b3.main();
   }
};
```

Semantics:

Sequential execution of statements and behaviors is the same as in standard C. The sequential control flow can be programmed using the standard C constructs **if-then-else**, **switch-case**, **goto**, **for**, **while**, etc.

The example above shows the trivial case of sequential, unconditional execution of three behaviors.

2.11 Parallel Execution

Purpose: Specification of concurrency

Synopsis:

```
concurrent_statement:              /* Statement */
        ...
        | par compound_statement

compound_statement:                /* Statement */
        '{' '}'
        | '{' declaration_list '}'
        | '{' statement_list '}'
        | '{' declaration_list statement_list '}'
```

Example:

```
behavior B;

behavior B_par(void)
{
   B      b1, b2, b3;

   void main(void)
   {
      par{ b1.main();
           b2.main();
           b3.main();
         }
   }
};
```

Semantics:

Concurrent execution of statements can be specified with the **par** statement. Every statement in the compound statement block following the **par** keyword forms a new thread of control and is executed in parallel. The execution of the **par** statement completes when each thread of control has finished its execution.

Usually, concurrent execution is used in the behavioral hierarchy in order to execute instantiated behaviors in parallel. This is shown in the example above where the behaviors $b1$, $b2$ and $b3$ are running concurrently. The compound behavior *B_par* finishes when $b1$, $b2$ and $b3$ have completed.

Note that in simulation, concurrent threads of control are not really executed in parallel. Instead, the scheduler, which is part of the simulation run-time system, always executes one thread at a time and decides when to suspend and when to resume a thread depending on simulation time advance and synchronization points.

2.12 Pipelined Execution

Purpose: Explicit support for specification of pipelining

Synopsis:

```
storage_class:                       /* BasicType */
        ...
        | piped
        | storage_class piped

concurrent_statement:                /* Statement */
        ...
        | pipe compound_statement

compound_statement:                  /* Statement */
        '{' '}'
        | '{' declaration_list '}'
        | '{' statement_list '}'
        | '{' declaration_list statement_list '}'
```

Example:

```
behavior B(in int p1, out int p2);

behavior B_pipe(in int a, out int b)
{
   int          x;
   piped int    y;
   B            b1(a, x),
                b2(x, y),
                b3(y, b);

   void main(void)
   {
      pipe{ b1.main();
            b2.main();
            b3.main();
          }
   }
};
```

Semantics:

Pipelined execution, specified by the **pipe** statement, is a special form of concurrent execution. As is with the **par** statement, all statements in the compound statement block after the **pipe** keyword form a new thread of control. They are executed in a pipelined fashion (in parallel but obey the specification order). The **pipe** statement never finishes (except through abortion which is described in Section 2.14).

For example, as shown above, the behaviors $b1$, $b2$ and $b3$ form a pipeline of behaviors. In the first iteration, only $b1$ is executed. When $b1$ finishes the second iteration starts and $b1$ and $b2$ are executed in parallel. In the third iteration, after $b1$ and $b2$ have completed, $b3$ is executed in parallel with $b1$ and $b2$. Every next iteration is the same as the third iteration (iteration three is repeated forever).

In order to support buffered communication in pipelines, the **piped** storage class can be used for variables connecting pipeline stages. A variable with **piped** storage class can be thought of as a variable with two storages. Write access always writes to the first storage, read access reads from the second storage. The contents of the first storage are shifted to the second storage whenever a new iteration starts in the **pipe** statement.

In the example above, x is a standard variable connecting $b1$ (pipeline stage 1) with $b2$ (stage 2). This variable is not buffered, in other words, every access from stage 1 is immediately visible in stage 2. On the other hand, variable y connecting $b2$ and $b3$ is buffered. A result that is computed by behavior $b2$ and stored in y is available for processing by $b3$ in the next iteration when $b2$ already produces new data.

Note that the **piped** storage class can be specified n times defining a variable with n buffers. This can be used to transfer data over n stages synchronously with the pipeline.

2.13 Finite State Machine Execution

Purpose: Explicit support for specification of finite state machines and state transitions

Synopsis:

```
fsm_statement:                    /* Statement */
        fsm '{' '}'
        | fsm '{' transition_list '}'

transition_list:                  /* TransitionList */
        transition
        | transition_list transition

transition:                       /* Transition */
        identifier ':'
        | identifier ':' cond_branch_list
        | identifier ':' '{' '}'
        | identifier ':' '{' cond_branch_list '}'

cond_branch_list:                 /* TransitionList */
        cond_branch
        | cond_branch_list cond_branch

cond_branch:                      /* Transition */
        if '(' comma_expression ')' goto identifier ';'
        | goto identifier ';'
        | if '(' comma_expression ')' break ';'
        | break ';'
```

Example:

```
behavior B;

behavior B_fsm(in int a, in int b)
{
   B     b1, b2, b3;

   void main(void)
   {
     fsm{ b1: { if (b < 0)  break;
                if (b >= 0) goto b2;
              }
          b2: { if (a > 0)  goto b1;
                goto b3;
              }
```

```
            b3 : {  break ;
                 }
         }
   }
};
```

Semantics:

Finite State Machine (FSM) execution is a special form of sequential execution which allows explicit specification of state transitions. Both Mealy and Moore type finite state machines can be modeled with the **fsm** construct.

As shown in the synopsis section above, the **fsm** construct specifies a list of state transitions where the states are instantiated behaviors. A state transition is a triple $\langle current\_state, condition, next\_state\rangle$. The *current_state* and the *next_state* take the form of labels and denote behavior instances. The *condition* is an expression which has to be evaluated as **true** for the transition to become valid.

The execution of a **fsm** construct starts with the execution of the first behavior that is listed in the transition list ($b1$). Once the behavior has finished, its state transition determine the next behavior to be executed. The conditions of the transitions are evaluated in the order they are specified (first $b < 0$, then $b \geq 0$) and as soon as one condition is **true** the specified next behavior is started ($b2$ in case of $b = 1$). If none of the conditions is true the next behavior defaults to the next behavior listed (similar to a **case** statement without **break**). A **break** statement terminates the execution of the **fsm** construct.

Note that the body of the **fsm** construct does not allow arbitrary statements. As specified in the synopsis section, the grammar limits the state transitions to well-defined triples.

2.14 Exception Handling

Purpose: Support for abortion of execution and interrupt handling

Synopsis:

```
exception_statement:                /* Statement */
        try compound_statement exception_list_opt

exception_list_opt:                 /* ExceptionList */
        /* nothing */
        | exception_list

exception_list:                     /* ExceptionList */
        exception
        | exception_list exception

exception:                          /* Exception */
        trap paren_event_list compound_statement
        | interrupt paren_event_list compound_statement

paren_event_list:                   /* SymbolPtrList */
        event_list
        | '(' event_list ')'

event_list:                         /* SymbolPtrList */
        identifier
        | event_list ',' identifier
```

Example:

```
behavior B;

behavior B_except(in event e1, in event e2)
{
   B     b1, b2;

    void main(void)
       {
          try { b1.main(); }
              interrupt (e1) { b2.main(); }
              trap (e2)      { b1.main(); }
       }
};
```

Semantics:

The **try-trap-interrupt** construct deals with two types of exception handling: abortion (or trap) and interrupt.

With **try**, a behavior is made sensitive to the events listed with the **trap** and **interrupt** declarations. Whenever such an event occurs while executing the **try** behavior its execution is immediately suspended. For an **interrupt** event, the specified interrupt handler is executed and after its completion the execution of the **try** behavior is resumed. For a **trap** event, the suspended execution is aborted and the trap handler takes over the execution.

In the example above, whenever event $e1$ is notified during execution of behavior $b1$, the execution of $b1$ is immediately suspended and behavior $b2$ is started. When $b2$ finishes the execution of behavior $b1$ is resumed. Note that during execution of $b2$ the event $e1$ is ignored (the interrupt does not interrupt itself). Also, as soon as event $e2$ occurs while executing behavior $b1$, the current execution is aborted and $b1$ is restarted. If **try** and **trap** denote the same behavior, as is in this case $b1$, effectively a reset is modeled.

As a rule, **interrupt** and **trap** declarations are prioritized in the order they are listed. Always only the first listed exception that matches an event is executed.

2.15 Synchronization

Purpose: Support for synchronization of concurrent behaviors

Synopsis:

```
wait_statement:                    /* Statement */
        wait paren_event_list ';'

notify_statement:                  /* Statement */
        notify paren_event_list ';'
        | notifyone paren_event_list ';'

paren_event_list:                  /* SymbolPtrList */
        event_list
        | '(' event_list ')'

event_list:                        /* SymbolPtrList */
        identifier
        | event_list ',' identifier
```

Example:

```
event   e;

behavior b1(int x, event s)
{
   void main(void)
   {
      x = 42;
      notify s;
      ...
      notify(e, s);
   }
}

behavior b2(int x, event r)
{
   void main(void)
   {
      wait(r);
      printf("%d", x);
      ...
      wait(e, s);
   }
}
```

Semantics:

There are three statements to support synchronization between concurrent executing behaviors: **wait**, **notify** and **notifyone**. Each of these statements takes a list of events (described in Section 2.3) as argument.

The **wait** statement suspends the current behavior from execution until one of the specified events is notified by another behavior. The execution of the waiting behavior is then resumed.

Note that when waiting for a list of events, the **wait** statement provides no information to determine which of the specified events actually was notified. This limitation is not a bug, it is a feature of pure event semantics.

The **notify** statement triggers all specified events so that all behaviors waiting on one of those events can continue their execution. If currently no other behavior is waiting on the notified events the notification is ignored.

The **notifyone** statement acts similar as the **notify** statement but notifies exactly one behavior from all behaviors waiting on the specified events. Again, if there is no behavior waiting the notification has no effect.

2.16 Timing Specification

Purpose: Explicit specification of execution time, delay and timing constraints

Synopsis:

```
waitfor_statement:                /* Statement */
        waitfor time ';'

timing_statement:                 /* Statement */
        do compound_statement timing '{' constraint_list_opt '}'

constraint_list_opt:              /* ConstraintList */
        /* nothing */
        | constraint_list

constraint_list:                  /* ConstraintList */
        constraint
        | constraint_list constraint

constraint:                       /* Constraint */
        range '(' any_name ';' any_name ';' time_opt ';' time_opt ')' ';'

time_opt:                         /* Constant */
        /* nothing */
        | time

time:                             /* Expression */
        constant_expression
```

Example:

```
void ClockGen(int *clk, int *clk2)
{
   do { t1: { *clk = 1; *clk2 = 1; }
        t2: { *clk = 0; }
        t3: { *clk = 1; *clk2 = 0; }
        t4: { *clk = 0; }
      }
   timing
      { range(t1; t2; 110; 112);
        range(t2; t3; 110; 112);
        range(t3; t4; 110; 112);
        range(t1; t4; 332;    );
      }
}
```

Semantics:

There are two constructs that support the specification of timing (simulation time).

First, the **waitfor** statement specifies delay or execution time. Whenever the simulator reaches a **waitfor** statement, the execution of the current behavior is suspended. As soon as the simulation time is increased by the number of time units specified in the argument, the execution of the current behavior resumes.

Second, the **do-timing** construct can be used to specify timing constraints in terms of minimum and maximum times. In the construct, the **do** block defines labeled statements which must be executed according to the constraints specified in the **timing** block.

Timing constraints are specified with **range** statements. Each constraint consists of two labels linking the constraint to its actions, and a minimum and maximum time value. The minimum and maximum times are optional constant expressions which will be evaluated at compile time. If unspecified, the minimum time is taken as $-\infty$, the maximum time as $+\infty$.

The semantics of a statement **range**$(l1, l2, min, max)$ is the following: The statement labeled $l1$ is to be executed at least min time steps before, but not more than max time steps after the statement labeled with $l2$.

Please note that the **do-timing** construct basically is a standard compound statement with attached constraints. As such, it can be executed as any other compound statement.

However, a simulation runtime system is free to check whether all specified constraints hold. For example, during execution of the **do** block, the runtime system can create time stamps at each label. After the execution of the **do** block is completed, these time stamps can then be used to check the **range** constraints. Any violation of the specified constraints can be reported to the user, for example, with a runtime error message.

2.17 Binary Import

Purpose: Fast and easy reuse of library components

Synopsis:

```
import_definition:                /* void */
        import string_literal_list ';'

string_literal_list:              /* String */
        string
        | string_literal_list string
```

Example:

```
#include <stdio.h>
#include <stdlib.h>

import "Interfaces/I1";
import "Interfaces/I2";
import "Channels/PCI_Bus";
import "Components/MPEG_II";
```

Semantics:

For using components declared or defined in separate files of SpecC source code, two constructs are provided. First, the `#include` statement known from the standard C language can be used. It will be evaluated at preprocessing time by the C preprocessor.

Second, the **import** declaration provides an efficient way to incorporate already compiled components. Using the SpecC compiler, any SpecC source description can be compiled into a binary file (with suffix `.sir`) containing the SpecC Internal Representation. Such a file can be included using the **import** declaration which effectively integrates all declarations and definitions from the binary file into the current design representation.

The string argument of the **import** declaration denotes the file name of the binary component to be integrated. The actual search for the binary file is implementation dependent but usually involves applying the suffix `.sir` and searching in a list of specified directories.

2.18 Persistent Annotation

Purpose: Support for persistent design annotation; easy data exchange between refinement tools

Synopsis:

```
any_declaration:                    /* void */
        ...
        | note_definition

any_definition:                     /* void */
        ...
        | note_definition

note_definition:                    /* void */
        note any_name '=' annotation ';'
        | note any_name '.' any_name '=' annotation ';'

annotation:                         /* Constant */
        constant_expression

any_name:                           /* Name */
        identifier
        | typedef_name
        | behavior_name
        | channel_name
        | interface_name
```

Example:

```
/* C style comment, not persistent */
// C++ style comment, not persistent

note Author      = "Rainer Doemer";
note Date        = "Wed Dec 30 21:46:23 PST 1998";

const int x = 42;
struct S { int a, b; float f; };

note x.Size      = sizeof(x);
note S.Bits      = sizeof(struct S) * 8;

behavior B(in int a, out int b)
{
   note Version   = 1.1;

```

```
17      void main(void)
18      {
19          l1: b = 2 * a;
20              waitfor(10);
21          l2: b = 3 * a;
22
23          note NumOps  = 3;
24          note l1.OpID = 1;
25          note l2.OpID = 3;
26      }
27  };
28  note B.AreaCost = 12345;
```

Semantics:

SpecC, as does any other programming language, allows comments in the source code to annotate the description. In particular, SpecC supports the same comment styles as C++, which are comments enclosed in `/*` and `*/` delimiters as well as comments after `//` up to the end of the line (see lines 1 and 2 in the example above). These comments are not persistent, which means, they are not stored in the SpecC Internal Representation.

Using the **note** definition, a persistent annotation can be attached to any symbol, label, and user-defined type. An annotation consists of a name and a note. The note can be any type of constant or constant expression (evaluated at compile time).

Names of notes have their own name space. There is no name conflict possible with symbols, user-defined types or labels.

There are two ways to define an annotation. First, a note can be attached to the current scope. This way global notes (lines 4 and 5 in the example), notes at classes (line 15), notes at methods (line 23), and notes at user-defined types can be defined.

Second, the object a note will be attached to can be named explicitly by preceding the note name with the object name and a dot. In the example above, this style is used to define the notes at variable x (line 10), structure S (line 11), and labels $l1$ and $l2$ (lines 24 and 25).

3 Summary

The SpecC Language Reference Manual defines the syntax and semantics of the SpecC language.

The SpecC language is designed to model embedded systems at system level. It is based on the ANSI-C programming language and uses additional constructs to support the requirements of modeling embedded systems. In Section 2, these additional constructs were enumerated and formally defined. In summary, these constructs add specific support for modeling system-level concepts, including behavioral hierarchy, concurrency, state transitions, timing, and exception handling.

For further information about the SpecC language, please refer to [3, 4, 5, 6, 7].

A SpecC Keywords and Tokens

In this section, a complete list of the SpecC keywords and tokens is defined. The following subsections use the `lex` syntax as the formal notation.

A.1 Lexical Rules

The following lexical rules are used to make the definitions below more understandable.

```
delimiter          [ \t\b\r]
newline            [\n\f\v]
whitespace         {delimiter}+
ws                 {delimiter}*
ucletter           [A-Z]
lcletter           [a-z]
letter             ({ucletter}|{lcletter})
digit              [0-9]
bindigit           [01]
octdigit           [0-7]
hexdigit           [0-9a-fA-F]
identifier         (({letter}|"_")({letter}|{digit}|"_")*)
integer            {digit}+
binary             {bindigit}+
decinteger         [1-9]{digit}*
octinteger         "0"{octdigit}*
hexinteger         "0"[xX]{hexdigit}+
decinteger_u       {decinteger}[uU]
octinteger_u       {octinteger}[uU]
hexinteger_u       {hexinteger}[uU]
decinteger_l       {decinteger}[lL]
octinteger_l       {octinteger}[lL]
hexinteger_l       {hexinteger}[lL]
decinteger_ul      {decinteger}("ul"|"lu"|"uL"|"Lu"|"Ul"|"lU"|"UL"|"LU")
octinteger_ul      {octinteger}("ul"|"lu"|"uL"|"Lu"|"Ul"|"lU"|"UL"|"LU")
hexinteger_ul      {hexinteger}("ul"|"lu"|"uL"|"Lu"|"Ul"|"lU"|"UL"|"LU")
decinteger_ll      {decinteger}("ll"|"LL")
octinteger_ll      {octinteger}("ll"|"LL")
hexinteger_ll      {hexinteger}("ll"|"LL")
decinteger_ull     {decinteger}("ull"|"llu"|"uLL"|"LLu"|"Ull"|"llU"|"ULL"|"LLU")
octinteger_ull     {octinteger}("ull"|"llu"|"uLL"|"LLu"|"Ull"|"llU"|"ULL"|"LLU")
hexinteger_ull     {hexinteger}("ull"|"llu"|"uLL"|"LLu"|"Ull"|"llU"|"ULL"|"LLU")
octchar            "\\"{octdigit}{1,3}
hexchar            "\\x"{hexdigit}+
exponent           [eE][+-]?{integer}
fraction           {integer}
float1             {integer}"."{fraction}?({exponent})?
```

```
float2          "."{fraction}({exponent})?
float3          {integer}{exponent}
float           {float1}|{float2}|{float3}
float_f         {float}[fF]
float_l         {float}[lL]
bitvector       {binary}("b"|"B")
bitvector_u     {binary}("ub"|"bu"|"uB"|"Bu"|"Ub"|"bU"|"UB"|"BU")
cppstart        {ws}"#"{ws}
cppflag         {whitespace}[1-4]
cppfile         "\""[ !#-~]*"\""
cpplineno       ^{cppstart}{integer}{whitespace}{cppfile}{cppflag}*{ws}{newline}
cpppragma       ^{cppstart}"pragma"{ws}.*
cppdirective    ^{cppstart}.*
```

A.2 Comments

In addition to the standard C style comments, the SpecC language also supports C++ style comments. Everything following two slash-characters is ignored until the end of the line.

```
"/*" <anything> "*/"      /* ignore comment */
"//" <anything> "\n"      /* ignore comment */
```

A.3 String and Character Constants

SpecC follows the standard C/C++ conventions for encoding character and string constants. The following escape sequences are recognized:

```
"\n"            /* newline              (0x0a) */
"\t"            /* tabulator            (0x09) */
"\v"            /* vertical tabulator   (0x0b) */
"\b"            /* backspace            (0x08) */
"\r"            /* carriage return      (0x0d) */
"\f"            /* form feed            (0x0c) */
"\a"            /* bell                 (0x07) */
{octchar}       /* octal encoded character */
{hexchar}       /* hexadecimal encoded character */
```

A.4 White space and Preprocessor Directives

As usual, white space in the source code is ignored. Preprocessor directives are handled by the C preprocessor (`cpp`) and are therefore eliminated from the SpecC source code when it is read by the scanner. As a special case, `pragma` directives, which are still left after preprocessing, are simply ignored.

```
{newline}       /* skip */
{whitespace}    /* skip */
{cpplineno}     /* acknowledge */
{cpppragma}     /* ignore */
{cppdirective}  /* error */
```

A.5 Keywords

The SpecC language recognizes the following ANSI-C keywords:

```
"auto"          { TOK_AUTO }
"break"         { TOK_BREAK }
"case"          { TOK_CASE }
"char"          { TOK_CHAR }
"const"         { TOK_CONST }
"continue"      { TOK_CONTINUE }
"default"       { TOK_DEFAULT }
"do"            { TOK_DO }
"double"        { TOK_DOUBLE }
"else"          { TOK_ELSE }
"enum"          { TOK_ENUM }
"extern"        { TOK_EXTERN }
"float"         { TOK_FLOAT }
"for"           { TOK_FOR }
"goto"          { TOK_GOTO }
"if"            { TOK_IF }
"int"           { TOK_INT }
"long"          { TOK_LONG }
"register"      { TOK_REGISTER }
"return"        { TOK_RETURN }
"short"         { TOK_SHORT }
"signed"        { TOK_SIGNED }
"sizeof"        { TOK_SIZEOF }
"static"        { TOK_STATIC }
"struct"        { TOK_STRUCT }
"switch"        { TOK_SWITCH }
"typedef"       { TOK_TYPEDEF }
"union"         { TOK_UNION }
"unsigned"      { TOK_UNSIGNED }
"void"          { TOK_VOID }
"volatile"      { TOK_VOLATILE }
"while"         { TOK_WHILE }
```

In addition, the following SpecC keywords are recognized:

```
"behavior"        { TOK_BEHAVIOR }
"bit"             { TOK_BIT }
"bool"            { TOK_BOOL }
"channel"         { TOK_CHANNEL }
"delta"           { TOK_DELTA }
"event"           { TOK_EVENT }
"false"           { TOK_FALSE }
"fsm"             { TOK_FSM }
"implements"      { TOK_IMPLEMENTS }
"import"          { TOK_IMPORT }
"in"              { TOK_IN }
"inout"           { TOK_INOUT }
"interface"       { TOK_INTERFACE }
"interrupt"       { TOK_INTERRUPT }
"note"            { TOK_NOTE }
"notify"          { TOK_NOTIFY }
"notifyone"       { TOK_NOTIFYONE }
"out"             { TOK_OUT }
"par"             { TOK_PAR }
"pipe"            { TOK_PIPE }
"piped"           { TOK_PIPED }
"range"           { TOK_RANGE }
"this"            { TOK_THIS }
"timing"          { TOK_TIMING }
"trap"            { TOK_TRAP }
"true"            { TOK_TRUE }
"try"             { TOK_TRY }
"wait"            { TOK_WAIT }
"waitfor"         { TOK_WAITFOR }
```

Also, for future extensions, the following tokens are reserved. These cannot be used in any SpecC program.

```
"asm"             { /* reserved */ }
"catch"           { /* reserved */ }
"class"           { /* reserved */ }
"const_cast"      { /* reserved */ }
"delete"          { /* reserved */ }
"dynamic_cast"    { /* reserved */ }
"explicit"        { /* reserved */ }
"export"          { /* reserved */ }
"friend"          { /* reserved */ }
"inline"          { /* reserved */ }
"mutable"         { /* reserved */ }
"namespace"       { /* reserved */ }
"new"             { /* reserved */ }
"operator"        { /* reserved */ }
```

```
"private"         { /* reserved */ }
"protected"       { /* reserved */ }
"public"          { /* reserved */ }
"reinterpret_cast" { /* reserved */ }
"static_cast"     { /* reserved */ }
"template"        { /* reserved */ }
"throw"           { /* reserved */ }
"typeid"          { /* reserved */ }
"typename"        { /* reserved */ }
"using"           { /* reserved */ }
"virtual"         { /* reserved */ }
```

SpecC supports all standard ANSI-C operators. The following multi-character operators are recognized as keywords (one token):

```
"->"              { TOK_ARROW }
"++"              { TOK_INCR }
"--"              { TOK_DECR }
"<<"              { TOK_SHIFTLEFT }
">>"              { TOK_SHIFTRIGHT }
"<="              { TOK_LE }
">="              { TOK_GE }
"=="              { TOK_EQ }
"!="              { TOK_NE }
"&&"              { TOK_ANDAND }
"||"              { TOK_OROR }
"..."             { TOK_ELLIPSIS }
"*="              { TOK_MULTASSIGN }
"/="              { TOK_DIVASSIGN }
"%="              { TOK_MODASSIGN }
"+="              { TOK_PLUSASSIGN }
"-="              { TOK_MINUSASSIGN }
"<<="             { TOK_SLASSIGN }
">>="             { TOK_SRASSIGN }
"&="              { TOK_ANDASSIGN }
"^="              { TOK_EORASSIGN }
"|="              { TOK_ORASSIGN }
.                 { <single character> }
```

A.6 Tokens with Values

The following is a complete list of all tokens that carry values.

```
{identifier}              { TOK_IDENTIFIER }
{decinteger}              { TOK_INTEGER }
```

```
{octinteger}            { TOK_INTEGER }
{hexinteger}            { TOK_INTEGER }
{decinteger_u}          { TOK_INTEGER }
{octinteger_u}          { TOK_INTEGER }
{hexinteger_u}          { TOK_INTEGER }
{decinteger_l}          { TOK_INTEGER }
{octinteger_l}          { TOK_INTEGER }
{hexinteger_l}          { TOK_INTEGER }
{decinteger_ul}         { TOK_INTEGER }
{octinteger_ul}         { TOK_INTEGER }
{hexinteger_ul}         { TOK_INTEGER }
{decinteger_ll}         { TOK_INTEGER }
{octinteger_ll}         { TOK_INTEGER }
{hexinteger_ll}         { TOK_INTEGER }
{decinteger_ull}        { TOK_INTEGER }
{octinteger_ull}        { TOK_INTEGER }
{hexinteger_ull}        { TOK_INTEGER }
{float}                 { TOK_FLOATING }
{float_f}               { TOK_FLOATING }
{float_l}               { TOK_FLOATING }
{bitvector}             { TOK_BITVECTOR }
{bitvector_u}           { TOK_BITVECTOR }
<any_character>         { TOK_CHARACTER }
```

B The SpecC Grammar

This section contains the complete grammar of the SpecC language. For formal notation, the `yacc` syntax style is used. Note that most of this grammar actually describes the C programming language[1]. Rules in the grammar added to support SpecC constructs are marked with comments.

B.1 Token with Values

```
identifier :                          /* Name */
        TOK_IDENTIFIER

typedef_name :                        /* Name */
        TOK_TYPEDEFNAME

behavior_name :                       /* Name */
        TOK_BEHAVIORNAME

channel_name :                        /* Name */
        TOK_CHANNELNAME

interface_name :                      /* Name */
        TOK_INTERFACENAME

integer :                             /* Const */
        TOK_INTEGER

floating :                            /* Const */
        TOK_FLOATING

character :                           /* Const */
        TOK_CHARACTER

string :                              /* String */
        TOK_STRING

bitvector :                           /* Const */
        TOK_BITVECTOR
```

B.2 Constants

```
constant :                            /* Constant */
```

[1]The SpecC grammar presented here is based on a ANSI-C grammar developed by J. A. Roskind. Use of that grammar is permitted if the following statement is preserved: "Portions Copyright (c) 1989, 1990 James A. Roskind".

```
        integer
        | floating
        | character
        /*** SpecC-only: boolean constants ***/
        | TOK_FALSE
        | TOK_TRUE
        /*** SpecC-only: bitvector constant ***/
        | bitvector
        | string_literal_list

string_literal_list:            /* String */
        string
        | string_literal_list string
```

B.3 Expressions

```
primary_expression:             /* Expression */
        identifier
        | constant
        | '(' comma_expression ')'
        /*** SpecC-only: untimed timing ***/
        | TOK_DELTA
        /*** SpecC-only: class self reference ***/
        | TOK_THIS

postfix_expression:             /* Expression */
        primary_expression
        | postfix_expression '[' comma_expression ']'
        | postfix_expression '(' ')'
        | postfix_expression '(' argument_expression_list ')'
        | postfix_expression '.' member_name
        | postfix_expression TOK_ARROW member_name
        | postfix_expression TOK_INCR
        | postfix_expression TOK_DECR
        /*** SpecC-only: bitvector slicing ***/
        | postfix_expression '[' constant_expression ':' constant_expression ']'

member_name:                    /* Name */
        identifier
        | typedef_or_class_name

argument_expression_list:       /* ExpressionList */
        assignment_expression
        | argument_expression_list ',' assignment_expression

unary_expression:               /* Expression */
```

```
        postfix_expression
        | TOK_INCR unary_expression
        | TOK_DECR unary_expression
        | unary_operator cast_expression
        | TOK_SIZEOF unary_expression
        | TOK_SIZEOF '(' type_name ')'

unary_operator:                 /* ExpressionType */
        '&'
        | '*'
        | '+'
        | '-'
        | '~'
        | '!'

cast_expression:                /* Expression */
        unary_expression
        | '(' type_name ')' cast_expression

        /*** SpecC-only: bitvector concatenation ***/
concat_expression:              /* Expression */
        cast_expression
        | concat_expression '@' cast_expression

multiplicative_expression:      /* Expression */
        concat_expression
        | multiplicative_expression '*' concat_expression
        | multiplicative_expression '/' concat_expression
        | multiplicative_expression '%' concat_expression

additive_expression:            /* Expression */
        multiplicative_expression
        | additive_expression '+' multiplicative_expression
        | additive_expression '-' multiplicative_expression

shift_expression:               /* Expression */
        additive_expression
        | shift_expression TOK_SHIFTLEFT additive_expression
        | shift_expression TOK_SHIFTRIGHT additive_expression

relational_expression:          /* Expression */
        shift_expression
        | relational_expression '<' shift_expression
        | relational_expression '>' shift_expression
        | relational_expression TOK_LE shift_expression
        | relational_expression TOK_GE shift_expression

equality_expression:            /* Expression */
```

```
        relational_expression
        | equality_expression TOK_EQ relational_expression
        | equality_expression TOK_NE relational_expression

and_expression:                  /* Expression */
        equality_expression
        | and_expression '&' equality_expression

exclusive_or_expression:         /* Expression */
        and_expression
        | exclusive_or_expression '^' and_expression

inclusive_or_expression:         /* Expression */
        exclusive_or_expression
        | inclusive_or_expression '|' exclusive_or_expression

logical_and_expression:          /* Expression */
        inclusive_or_expression
        | logical_and_expression TOK_ANDAND inclusive_or_expression

logical_or_expression:           /* Expression */
        logical_and_expression
        | logical_or_expression TOK_OROR logical_and_expression

conditional_expression:          /* Expression */
        logical_or_expression
        | logical_or_expression '?' comma_expression ':' conditional_expression

assignment_expression:           /* Expression */
        conditional_expression
        | unary_expression assignment_operator assignment_expression

assignment_operator:             /* ExpressionType */
        '='
        | TOK_MULTASSIGN
        | TOK_DIVASSIGN
        | TOK_MODASSIGN
        | TOK_PLUSASSIGN
        | TOK_MINUSASSIGN
        | TOK_SLASSIGN
        | TOK_SRASSIGN
        | TOK_ANDASSIGN
        | TOK_EORASSIGN
        | TOK_ORASSIGN

comma_expression:                /* Expression */
        assignment_expression
        | comma_expression ',' assignment_expression
```

```
constant_expression :               /* Expression */
        conditional_expression

comma_expression_opt :              /* Expression */
        /* nothing */
        | comma_expression
```

B.4 Declarations

```
declaration :                       /* void */
        sue_declaration_specifier ';'
        | sue_type_specifier ';'
        | declaring_list ';'
        | default_declaring_list ';'

default_declaring_list :            /* DeclarationSpec */
        declaration_qualifier_list identifier_declarator initializer_opt
        | type_qualifier_list identifier_declarator initializer_opt
        | default_declaring_list ',' identifier_declarator initializer_opt

declaring_list :                    /* DeclarationSpec */
        declaration_specifier declarator initializer_opt
        | type_specifier declarator initializer_opt
        | declaring_list ',' declarator initializer_opt

declaration_specifier :             /* DeclarationSpec */
        basic_declaration_specifier
        | sue_declaration_specifier
        | typedef_declaration_specifier

type_specifier :                    /* Type */
        basic_type_specifier
        | sue_type_specifier
        | typedef_type_specifier

declaration_qualifier_list :        /* BasicType */
        storage_class
        | type_qualifier_list storage_class
        | declaration_qualifier_list declaration_qualifier

type_qualifier_list :               /* BasicType */
        type_qualifier
        | type_qualifier_list type_qualifier

declaration_qualifier :             /* BasicType */
```

```
        storage_class
        | type_qualifier

type_qualifier:                 /* BasicType */
        TOK_CONST
        | TOK_VOLATILE

basic_declaration_specifier:    /* BasicType */
        declaration_qualifier_list basic_type_name
        | basic_type_specifier storage_class
        | basic_declaration_specifier declaration_qualifier
        | basic_declaration_specifier basic_type_name

basic_type_specifier:           /* BasicType */
        basic_type_name
        | type_qualifier_list basic_type_name
        | basic_type_specifier type_qualifier
        | basic_type_specifier basic_type_name

sue_declaration_specifier:      /* DeclarationSpec */
        declaration_qualifier_list elaborated_type_name
        | sue_type_specifier storage_class
        | sue_declaration_specifier declaration_qualifier

sue_type_specifier:             /* Type */
        elaborated_type_name
        | type_qualifier_list elaborated_type_name
        | sue_type_specifier type_qualifier

typedef_declaration_specifier:  /* DeclarationSpec */
        typedef_type_specifier storage_class
        | declaration_qualifier_list typedef_name
        | typedef_declaration_specifier declaration_qualifier

typedef_type_specifier:         /* Type */
        typedef_name
        | type_qualifier_list typedef_name
        | typedef_type_specifier type_qualifier

storage_class:                  /* BasicType */
        TOK_TYPEDEF
        | TOK_EXTERN
        | TOK_STATIC
        | TOK_AUTO
        | TOK_REGISTER
        /*** SpecC-only: piped modifier ***/
        | TOK_PIPED
```

```
basic_type_name:                   /* BasicType */
        TOK_INT
        | TOK_CHAR
        | TOK_SHORT
        | TOK_LONG
        | TOK_FLOAT
        | TOK_DOUBLE
        | TOK_SIGNED
        | TOK_UNSIGNED
        | TOK_VOID
        /*** SpecC-only: boolean type ***/
        | TOK_BOOL
        /*** SpecC-only: bit(vector) type ***/
        | TOK_BIT '[' constant_expression ':' constant_expression ']'
        /*** SpecC-only: event type ***/
        | TOK_EVENT

elaborated_type_name:              /* Type */
        aggregate_name
        | enum_name

aggregate_name:                    /* Type */
        aggregate_key '{' member_declaration_list '}'
        | aggregate_key identifier_or_typedef_name '{' member_declaration_list
                '}'
        | aggregate_key identifier_or_typedef_name

aggregate_key:                     /* UserTypeClass */
        TOK_STRUCT
        | TOK_UNION

member_declaration_list:           /* MemberList */
        member_declaration
        | member_declaration_list member_declaration

member_declaration:                /* MemberList */
        member_declaring_list ';'
        | member_default_declaring_list ';'
        /*** SpecC-only: note definition in member list ***/
        | note_definition

member_default_declaring_list:   /* MemberDeclSpec */
        type_qualifier_list member_identifier_declarator
        | member_default_declaring_list ',' member_identifier_declarator

member_declaring_list:             /* MemberDeclSpec */
        type_specifier member_declarator
        | member_declaring_list ',' member_declarator
```

```
member_declarator:                 /* MmbrDeclarator */
        declarator  bit_field_size_opt
        | bit_field_size

member_identifier_declarator:      /* MmbrDeclarator */
        identifier_declarator  bit_field_size_opt
        | bit_field_size

bit_field_size_opt:                /* Expression */
        /* nothing */
        | bit_field_size

bit_field_size:                    /* Expression */
        ':'  constant_expression

enum_name:                         /* Type */
        TOK_ENUM '{'  enumerator_list  '}'
        | TOK_ENUM identifier_or_typedef_name  '{'  enumerator_list  '}'
        | TOK_ENUM identifier_or_typedef_name

enumerator_list:                   /* MemberList */
        identifier_or_typedef_name  enumerator_value_opt
        | enumerator_list  ','  identifier_or_typedef_name  enumerator_value_opt

enumerator_value_opt:              /* Expression */
        /* nothing */
        | '='  constant_expression

parameter_type_list:               /* ParameterList */
        parameter_list
        | parameter_list  ','  TOK_ELLIPSIS

parameter_list:                    /* ParameterList */
        parameter_declaration
        | parameter_list  ','  parameter_declaration
        /*** SpecC-only: interface  parameter ***/
        | interface_parameter
        | parameter_list  ','  interface_parameter

parameter_declaration:             /* Parameter */
        declaration_specifier
        | declaration_specifier  abstract_declarator
        | declaration_specifier  identifier_declarator
        | declaration_specifier  parameter_typedef_declarator
        | declaration_qualifier_list
        | declaration_qualifier_list  abstract_declarator
        | declaration_qualifier_list  identifier_declarator
```

```
        | type_specifier
        | type_specifier  abstract_declarator
        | type_specifier  identifier_declarator
        | type_specifier  parameter_typedef_declarator
        | type_qualifier_list
        | type_qualifier_list  abstract_declarator
        | type_qualifier_list  identifier_declarator

identifier_or_typedef_name:        /* Name */
        identifier
        | typedef_or_class_name

type_name:                         /* Type */
        type_specifier
        | type_specifier  abstract_declarator
        | type_qualifier_list
        | type_qualifier_list  abstract_declarator

initializer_opt:                   /* Initializer */
        /* nothing */
        | '=' initializer

initializer:                       /* Initializer */
        '{' initializer_list '}'
        | '{' initializer_list ',' '}'
        | constant_expression

initializer_list:                  /* InitializerList */
        initializer
        | initializer_list ',' initializer
```

B.5 Statements

```
statement:                         /* Statement */
        labeled_statement
        | compound_statement
        | expression_statement
        | selection_statement
        | iteration_statement
        | jump_statement
        /*** SpecC-only: SpecC statements ***/
        | spec_c_statement

labeled_statement:                 /* Statement */
        identifier_or_typedef_name ':' statement
        | TOK_CASE constant_expression ':' statement
```

```
        | TOK_DEFAULT ':' statement

compound_statement:             /* Statement */
        compound_scope '{' '}'
        | compound_scope '{' declaration_list '}'
        | compound_scope '{' statement_list '}'
        | compound_scope '{' declaration_list statement_list '}'

compound_scope:                 /* Scope */
        /* nothing */

declaration_list:               /* void */
        declaration
        | declaration_list declaration
        /*** SpecC-only: note definitions in compound statements ***/
        | note_definition
        | declaration_list note_definition

statement_list:                 /* StatementList */
        statement
        | statement_list statement
        /*** SpecC-only: note definitions in compound statements ***/
        | statement_list note_definition

expression_statement:           /* Statement */
        comma_expression_opt ';'

selection_statement:            /* Statement */
          TOK_IF '(' comma_expression ')' statement
        | TOK_IF '(' comma_expression ')' statement TOK_ELSE statement
        | TOK_SWITCH '(' comma_expression ')' statement

iteration_statement:            /* Statement */
        TOK_WHILE '(' comma_expression_opt ')' statement
        | TOK_DO statement TOK_WHILE '(' comma_expression ')' ';'
        | TOK_FOR '(' comma_expression_opt ';' comma_expression_opt ';'
                comma_expression_opt ')' statement

jump_statement:                 /* Statement */
        TOK_GOTO identifier_or_typedef_name ';'
        | TOK_CONTINUE ';'
        | TOK_BREAK ';'
        | TOK_RETURN comma_expression_opt ';'
```

B.6 External Definitions

```
translation_unit:                /* void */
        /* nothing */
        | external_definition_list

external_definition_list:        /* void */
        external_definition
        | external_definition_list external_definition

external_definition:             /* void */
        function_definition
        | declaration
        /*** SpecC-only: SpecC specific definitions ***/
        | spec_c_definition

function_definition:             /* void */
        identifier_declarator compound_statement
        | declaration_specifier declarator compound_statement
        | type_specifier declarator compound_statement
        | declaration_qualifier_list identifier_declarator compound_statement
        | type_qualifier_list identifier_declarator compound_statement

declarator:                      /* Declarator */
        identifier_declarator
        | typedef_declarator

typedef_declarator:              /* Declarator */
        paren_typedef_declarator
        | parameter_typedef_declarator

parameter_typedef_declarator:    /* Declarator */
        typedef_or_class_name
        | typedef_or_class_name postfixing_abstract_declarator
        | clean_typedef_declarator

clean_typedef_declarator:        /* Declarator */
        clean_postfix_typedef_declarator
        | '*' parameter_typedef_declarator
        | '*' type_qualifier_list parameter_typedef_declarator

clean_postfix_typedef_declarator:        /* Declarator */
        '(' clean_typedef_declarator ')'
        | '(' clean_typedef_declarator ')' postfixing_abstract_declarator

paren_typedef_declarator:        /* Declarator */
        paren_postfix_typedef_declarator
        | '*' '(' simple_paren_typedef_declarator ')'
        | '*' type_qualifier_list '(' simple_paren_typedef_declarator ')'
        | '*' paren_typedef_declarator
```

```
        | '*' type_qualifier_list paren_typedef_declarator

paren_postfix_typedef_declarator:       /* Declarator */
        '(' paren_typedef_declarator ')'
        | '(' simple_paren_typedef_declarator postfixing_abstract_declarator ')'
        | '(' paren_typedef_declarator ')' postfixing_abstract_declarator

simple_paren_typedef_declarator:        /* Declarator */
        typedef_or_class_name
        | '(' simple_paren_typedef_declarator ')'

identifier_declarator:          /* Declarator */
        unary_identifier_declarator
        | paren_identifier_declarator

unary_identifier_declarator:    /* Declarator */
        postfix_identifier_declarator
        | '*' identifier_declarator
        | '*' type_qualifier_list identifier_declarator

postfix_identifier_declarator:  /* Declarator */
        paren_identifier_declarator postfixing_abstract_declarator
        | '(' unary_identifier_declarator ')'
        | '(' unary_identifier_declarator ')' postfixing_abstract_declarator

paren_identifier_declarator:    /* Declarator */
        identifier
        | '(' paren_identifier_declarator ')'

abstract_declarator:            /* AbstrDeclarator */
        unary_abstract_declarator
        | postfix_abstract_declarator
        | postfixing_abstract_declarator

postfixing_abstract_declarator: /* AbstrDeclarator */
        array_abstract_declarator
        | '(' ')'
        | '(' parameter_type_list ')'

array_abstract_declarator:      /* AbstrDeclarator */
        '[' ']'
        | '[' constant_expression ']'
        | array_abstract_declarator '[' constant_expression ']'

unary_abstract_declarator:      /* AbstrDeclarator */
        '*'
        | '*' type_qualifier_list
        | '*' abstract_declarator
```

```
        | '*' type_qualifier_list abstract_declarator

postfix_abstract_declarator:    /* AbstrDeclarator */
        '(' unary_abstract_declarator ')'
        | '(' postfix_abstract_declarator ')'
        | '(' postfixing_abstract_declarator ')'
        | '(' unary_abstract_declarator ')' postfixing_abstract_declarator
```

B.7 SpecC Constructs

```
spec_c_definition:              /* void */
        import_definition
        | behavior_declaration
        | behavior_definition
        | channel_declaration
        | channel_definition
        | interface_declaration
        | interface_definition
        | note_definition

import_definition:              /* void */
        TOK_IMPORT string_literal_list ';'

behavior_declaration:           /* void */
        behavior_specifier port_list_opt implements_interface_opt ';'

behavior_definition:            /* void */
        behavior_specifier port_list_opt implements_interface_opt
                '{' internal_definition_list_opt '}' ';'

behavior_specifier:             /* Declarator */
        TOK_BEHAVIOR identifier

channel_declaration:            /* void */
        channel_specifier port_list_opt implements_interface_opt ';'

channel_definition:             /* void */
        channel_specifier port_list_opt implements_interface_opt
                '{' internal_definition_list_opt '}' ';'

channel_specifier:              /* Declarator */
        TOK_CHANNEL identifier

port_list_opt:                  /* ParameterList */
        /* nothing */
        | '(' ')'
```

```
        | '(' port_list ')'

port_list :                         /* ParameterList */
        port_declaration
        | port_list ',' port_declaration

port_declaration :                  /* Parameter */
        port_direction parameter_declaration
        | interface_parameter

port_direction :                    /* Direction */
        /* nothing */
        | TOK_IN
        | TOK_OUT
        | TOK_INOUT

interface_parameter :               /* Parameter */
        interface_name
        | interface_name identifier

implements_interface_opt :          /* SymbolPtrList */
        /* nothing */
        | TOK_IMPLEMENTS interface_list

interface_list :                    /* SymbolPtrList */
        interface_name
        | interface_list ',' interface_name

internal_definition_list_opt :      /* void */
        /* nothing */
        | internal_definition_list

internal_definition_list :          /* void */
        internal_definition
        | internal_definition_list internal_definition

internal_definition :               /* void */
        function_definition
        | declaration
        | instantiation
        | note_definition

instantiation :                     /* void */
        instance_declaring_list ';'

instance_declaring_list :           /* DeclarationSpec */
        behavior_or_channel instance_declarator
        | instance_declaring_list ',' instance_declarator
```

```
instance_declarator:            /* Declarator */
        identifier port_mapping_opt
        | typedef_or_class_name port_mapping_opt

behavior_or_channel:            /* DeclarationSpec */
        behavior_name
        | channel_name

port_mapping_opt:               /* PortMapList */
        /* nothing */
        | '(' ')'
        | '(' port_mapping_list ')'

port_mapping_list:              /* PortMapList */
        port_mapping
        | port_mapping_list ',' port_mapping

port_mapping:                   /* BitSliceList */
        bit_slice
        | port_mapping '&' bit_slice

bit_slice:                      /* BitSlice */
        identifier
        | identifier '[' constant_expression ':' constant_expression ']'
        | identifier '[' constant_expression ']'

interface_declaration:          /* void */
        interface_specifier ';'

interface_definition:           /* void */
        interface_specifier '{' internal_declaration_list_opt '}' ';'

interface_specifier:            /* Declarator */
        TOK_INTERFACE anyname

internal_declaration_list_opt:  /* void */
        /* nothing */
        | internal_declaration_list

internal_declaration_list:      /* void */
        internal_declaration
        | internal_declaration_list internal_declaration

internal_declaration:           /* void */
        declaration
        | note_definition
```

```
note_definition:                      /* void */
        TOK_NOTE any_name '=' note ';'
        | TOK_NOTE any_name '.' any_name '=' note ';'

note:                                 /* Constant */
        constant_expression

typedef_or_class_name:                /* Name */
        typedef_name
        | behavior_name
        | channel_name
        | interface_name

any_name:                             /* Name */
        identifier
        | typedef_name
        | behavior_name
        | channel_name
        | interface_name
```

B.8 SpecC Statements

```
spec_c_statement:                     /* Statement */
        concurrent_statement
        | fsm_statement
        | exception_statement
        | timing_statement
        | wait_statement
        | waitfor_statement
        | notify_statement

concurrent_statement:                 /* Statement */
        TOK_PAR compound_statement
        | TOK_PIPE compound_statement

fsm_statement:                        /* Statement */
        TOK_FSM '{' '}'
        | TOK_FSM '{' transition_list '}'

transition_list:                      /* TransitionList */
        transition
        | transition_list transition

transition:                           /* Transition */
        identifier ':'
        | identifier ':' cond_branch_list
```

```
        | identifier ':' '{' '}'
        | identifier ':' '{' cond_branch_list '}'

cond_branch_list:               /* TransitionList */
        cond_branch
        | cond_branch_list cond_branch

cond_branch:                    /* Transition */
        TOK_IF '(' comma_expression ')' TOK_GOTO identifier ';'
        | TOK_GOTO identifier ';'
        | TOK_IF '(' comma_expression ')' TOK_BREAK ';'
        | TOK_BREAK ';'

exception_statement:            /* Statement */
        TOK_TRY compound_statement exception_list_opt

exception_list_opt:             /* ExceptionList */
        /* nothing */
        | exception_list

exception_list:                 /* ExceptionList */
        exception
        | exception_list exception

exception:                      /* Exception */
        TOK_TRAP paren_event_list compound_statement
        | TOK_INTERRUPT paren_event_list compound_statement

paren_event_list:               /* SymbolPtrList */
        event_list
        | '(' event_list ')'

event_list:                     /* SymbolPtrList */
        event
        | event_list ',' event

event:                          /* SymbolPtr */
        identifier

timing_statement:               /* Statement */
        TOK_DO compound_statement TOK_TIMING '{' constraint_list_opt '}'

constraint_list_opt:            /* ConstraintList */
        /* nothing */
        | constraint_list

constraint_list:                /* ConstraintList */
        constraint
```

```
        | constraint_list constraint

constraint:                     /* Constraint */
        TOK_RANGE '(' any_name ';' any_name ';' time_opt ';' time_opt ')' ';'

time_opt:                       /* Constant */
        /* nothing */
        | time

time:                           /* Expression */
        constant_expression

wait_statement:                 /* Statement */
        TOK_WAIT paren_event_list ';'

waitfor_statement:              /* Statement */
        TOK_WAITFOR time ';'

notify_statement:               /* Statement */
        TOK_NOTIFY paren_event_list ';'
        | TOK_NOTIFYONE paren_event_list ';'
```

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