Elaborator and Runtime Library – A Metropolis Backend Tool

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Outline

- Elaborator and the elaboration process
  - Implementation
  - Network elaboration
  - Constraint elaboration
- Runtime library
  - What is runtime library
  - How to use runtime library
- Applications of elaborated constraints
  - Annotation trace generation
  - LOC checker generation

What is Elaborator?

- A backend tool that can be called by the user or other backend tools
- Input: MMM source code/abstract syntax trees
- Output: the structure of the network
  - Object nodes in the network (e.g. processes)
  - Connections between objects
  - Refinement hierarchy
  - Constraint instances (constraint elaboration)
  - Resolved runtime structural keywords, e.g. getconnectionnum, getconnectionsrc, ..., etc

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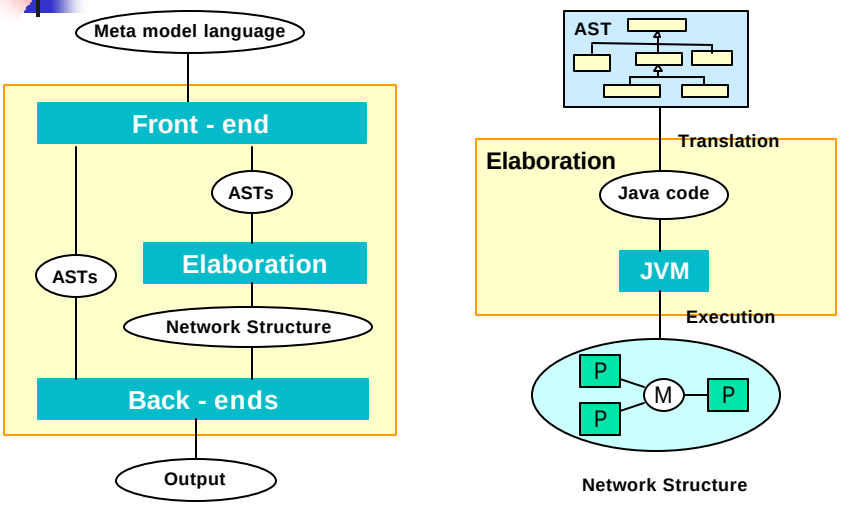
The Elaboration Process



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Implementation of Elaborator

- Translate MMM objects (e.g. process, medium) to Java classes
- Top-level netlist is instantiated, and all the other objects are instantiated in turn
- Only constructors of the objects in the network are executed
- The network is built using the runtime library by executing the Java code
- Location: metropolis.metamodel.backends.elaborator

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An Example of Network Elaboration

```
public netlist IwIr {
  public IwIr(String name) {
    …
    int numP  = 2;
    for (int i = 0; i < numP ; i++) {
      XX p = new XX("P"+i);
      addcomponent(p, this, "P"+i);
      connect(p, port1, m);
      connect(p, port0, r); }
    …
  }
}
```

MMM Source Code

```
public class IwIr extends metamodel.lang.Netlist {
  public IwIr(String name) {
    super(name);
    …
    int numP  = 2;
    for (int i = 0; i < numP ; i++) {
      XX p = new XX("P" + i);
      Network.net.addComponent(p, this, "P" + i);
      Network.net.connect(p, "port1", m);
      Network.net.connect(p, "port0", r); }
    …
  }
}
```

Java Code

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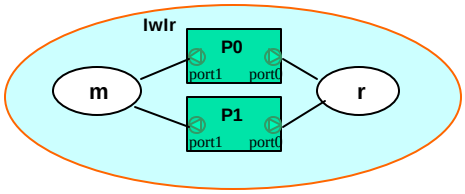
An Example of Network Elaboration (cont'd)



Network structure generated by Java execution and represented by runtime library classes

```
netlist test.IwIr {
 o Instance name: top_level_netlist
 o component name: null
 o Components:
     - P0 (instance name: P0)
     - P1 (instance name: P1)
     - m (instance name: m)
     - r (instance name: r)
 o Not refined by a netlist
 o Does not refine any node
 o No constraints
}
process test.XX {
 o Instance name: P0
 o component name: P0
 o Ports:
     test.IntWriter port1
     test.IntReader port0
 o Not refined by a netlist
 o Output connections:
     - P0 --(test.IntWriter port1)--> m
     - P0 --(test.IntReader port0)--> r
 o No constraints
}
…
```

The print-out of the elaborated network

An Example of Constraint Elaboration

```
public netlist sumnet {
  …
  constraint{
    event Wevent = beg (…);
    event Revent = end (…);
    for(j = 0; j < m; j ++)
      loc(forall (int i) k[j]@(Wevent,i) == k[j]@(Revent,i));
  }
  …
}
```

MMM Source Code

```
public class sumnet extends metamodel.lang.Netlist {
  public IwIr(String name) {
  …
  /*constraint block*/ {
    Constraint __tmpConstraint;
    Event Wevent = new Event(…);
    Event Revent = new Event(…));
    for(j = 0; j < m; j ++) {
        // loc(forall (int i) k[j]@(Wevent,i) == k[j]@(Revent,i));
        tmpConstraint = new Constraint(Constraint.LOC);
        Network.net.getNode(this).addConstraint(__tmpConstraint);
        tmpConstraint.addEvent(Wevent );
        Network.net.addAnnotation(Wevent ,"k[" + i + "]");
        tmpConstraint.addEvent(C_start);
        Network.net.addAnnotation(Revent ,"k[" + i + "]");
  }
  …
}}
```

Java Code

- If m = 2, there are actually 2 different constraint instances

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An Example of Constraint Elaboration (cont'd)

```
netlist test.sumnet {
  o Instance name: top_level_netlist
  o component name: null
  o Components:
       …
       …
  o Not refined by a  netlist
  o Does not refine any node
  o Constraints:
       - LOC Constraint (# 0)
         o Container: top_level_netlist
         o Event references:
           - beg(datagen1, y2bf1.tokenLabel)
           - beg(sum1, bf2y1.tokenLabel)

       - LOC Constraint (# 1)
         o Container: top_level_netlist
         o Event references:
           - beg(datagen1, y2bf1.tokenLabel)
           - beg(sum1, bf2y1.tokenLabel)

}

*** List of annotations ***
  o beg(sum1, bf2y1.tokenLabel) k[0]
  o beg(datagen1, y2bf1.tokenLabel) k[1]
  o beg(sum1, bf2y1.tokenLabel) k[0]
  o beg(datagen1, y2bf1.tokenLabel) k[1]
```

The print-out of the elaborated constraints

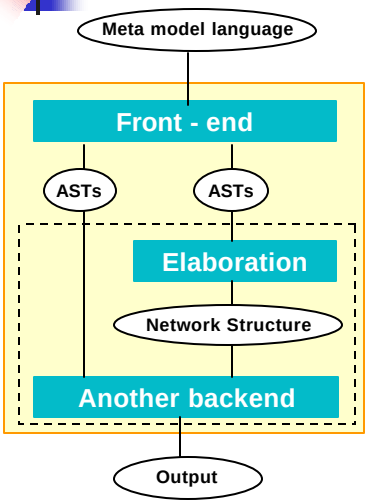
- Constraints are indexed in an node
- Event references are saved
- A list of annotations are saved in the network

Advantages of Elaboration

- Get the network structure before doing anything else
- Resolve runtime keywords or variables
- Useful to many other backend tools
  - Simulation – SystemC
  - Verification – Promela
  - Constraint monitoring or checking

  … etc

How to Use Elaborator



- Elaborated network is normally utilized by other backend tools
- Call elaborator and get the elaborated network
- Use runtime library API to access and manipulate the elaborated network
- Example: *SystemCBackend* class is defined as a subclass of *ElaboratorBackend* class

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Runtime Library

- Represent and manipulate the elaborated network structure
- A set of Java classes located in metropolis.metamodel.runtime
- Java classes in runtime library:
  - Network – describe the whole elaborated network
  - MMType – specify a particular node type, e.g. a process type or a netlist type
  - INode – represent an object node, e.g. a medium instance
  - INetlist – represent an object of netlist, e.g. a netlist instance

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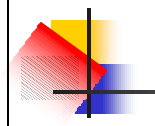

Runtime Library (cont'd)

- More Java classes in runtime library:
  - MMPort – specify a port type
  - IPort – represent a port instance
  - Connection – specify a connection between 2 nodes through ports
  - Event – represent an event reference, e.g. beg(process, medium.label)
  - Constraint – represent a constraint instance

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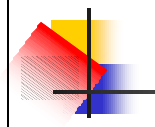

Runtime Library (cont'd)

- The network structure can be accessed by calling runtime library APIs, for example:
  - Network.getNodes() – get a list of nodes in the network
  - Network.getNetlist() – get a particular netlist by name
  - Network.show() – return a string that describes the network
- The network structure can also be modified by calling runtime library APIs, for example:
  - Network.flatten() – flatten the elaborated network into a network where refined nodes and connections are replaced by their refinements

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LOC Constraints in MMM

- LOC is a transaction-level quantitative constraint language
- Directly supported by MMM syntex
- Using MMM keywords *constraint* and *loc*
- For example (a latency constraint):

```
constraint {
        event P0_start = beg(p0, p0.start);
        event P0_finish = beg(p0, p0.finish);

        loc(forall (int i) t@(P0_finish,i) - t@(P0_start, i)  <= 20 );
}
```

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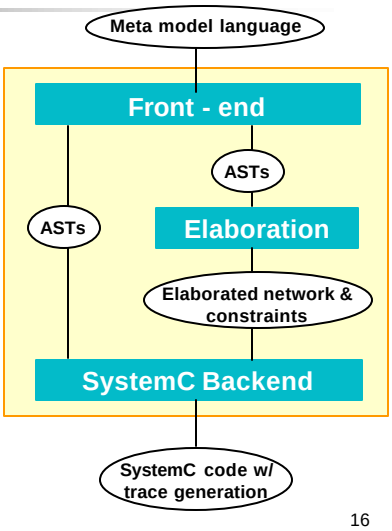
Annotation Trace Generation

- An application of elaborated constraints
- Utilize elaborated constraints and annotations
- Trace generation – insert "print" statements into SystemC code



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An Example of Annotation Trace Generation

```
constraint {
    event P1_start = beg(p1, p1.start);
    event C_start = beg(c, c.start);

    loc(forall (int i) w@(P1_start,i) == w@(C_start, i) );
}
```

A Constraint in MMM

```
*** List of annotations ***
  o beg(p1, p1.start)  w
  o beg(c, c.start)  w
```

Elaborated annotations

SystemC Backend

SystemC Simulation w/ trace generation

```
BEG_Consumer_Consumer_start 0
BEG_Producer1_Producer1_start 0
BEG_Producer1_Producer1_start 1
BEG_Producer1_Producer1_start 2
BEG_Consumer_Consumer_start 1
BEG_Producer1_Producer1_start 3
BEG_Consumer_Consumer_start 2
BEG_Producer1_Producer1_start 4
BEG_Consumer_Consumer_start 3
⋮
```

Trace from SystemC Simulation

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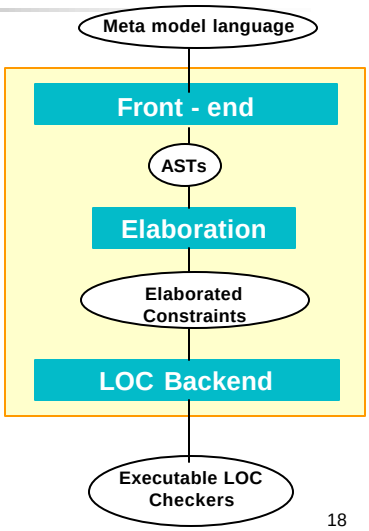
LOC Checker Generation

- Another example of elaborated constraints
- Utilize elaborated constraints and annotations
- We are still working on it



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A Complete Example of LOC Checking

```
public netlist IwIr {
  public IwIr(String name) {
    …
    constraint {
      event P1_start = beg(p1, p1.start);
      event C_start = beg(c, c.start);

      loc(forall (int i) w@(P1_start,i) == w@(C_start, i) );
    }
    …
  }
}
```

MMM Source Code

```
public class IwIr extends metamodel.lang.Netlist {
  public IwIr(String name) {
  …
  /*constraint block*/ {
    Constraint __tmpConstraint;
    Event P1_start = new Event(Event.BEG, p1, p1, "start");
    Event C_start = new Event(Event.BEG, c, c, "start");

    // loc(forall (int i) w@(P1_start,i) == r@(C_start, i+1) );
    tmpConstraint = new Constraint(Constraint.LOC);
    Network.net.getNode(this).addConstraint(__tmpConstraint);
    tmpConstraint.addEvent(P1_start);
    Network.net.addAnnotation(P1_start, "w");
    tmpConstraint.addEvent(C_start);
    Network.net.addAnnotation(C_start, " w");
  }
  …
}}
```

Java Code

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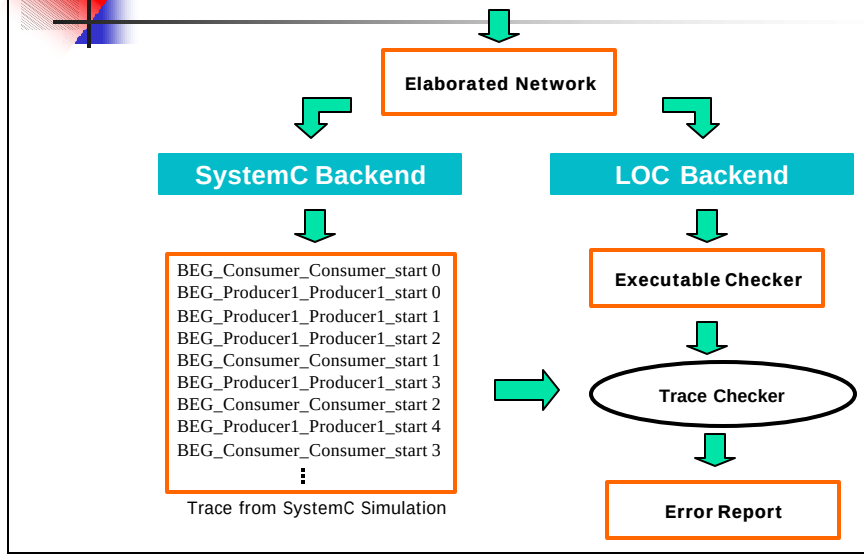
A Complete Example of LOC Checking



Trace from SystemC Simulation

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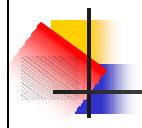

To Be Done

- Integrate LOC monitors into SystemC simulation
- Resolve runtime structural keywords, e.g. getconnectionnum, getconnectionsrc, ...
- Check or monitor LTL constraints

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