An EMOF-Compliant Abstract Syntax for Bigraphs

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Graphs as Models (GaM) @ ETAPS 2016

Bigraphs and Bigraphical Reactive Systems

The idea of bigraphs:

- Fundamental concepts: locality (placing) and connectivity (linking)
- Constituents of a bigraph:
  - **Place graph:** Forest defined over a set of nodes representing entities in terms of a containment structure.
  - **Link graph:** Hypergraph composed over the same set of nodes representing arbitrary linking among entities.

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Bigraphical reactive systems:

- Possible local reconfigurations expressed as a set of reaction rules.
- Rewriting rules which consist of two bigraphs; redex and reactum.
- Redex specifies a bigraphical pattern whose occurrence found in a "host bigraph" enables replacement by the reactum.

Bigraphs as Domain-specific Language for Simulation and Development

What's readily available...

- Fundamental modeling formalism
- Rich theory, shown to be general enough as a meta-calculus (can embed existing process calculi)
- Precise visual syntax and algebraic notation (textual syntax)

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What's missing...

- Bigraphs yet lack a definition of an abstract syntax
- Available research prototypes use proprietary formats and are thus poorly integrated
- Hampers the exchange of models across tool boundaries and the development of sophisticated tool chains

Outline

Preliminaries:

- The Idea of Bigraphs
- Graph-based Representation of EMOF Models

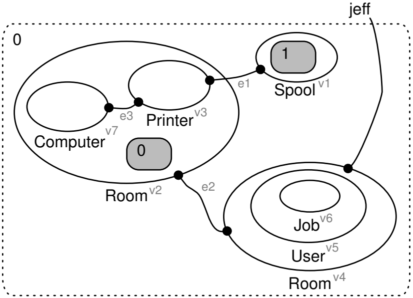
Contributions:

- A Canonical Mapping of Bigraphs to Typed Graphs
- Handling of Application-specific Variability

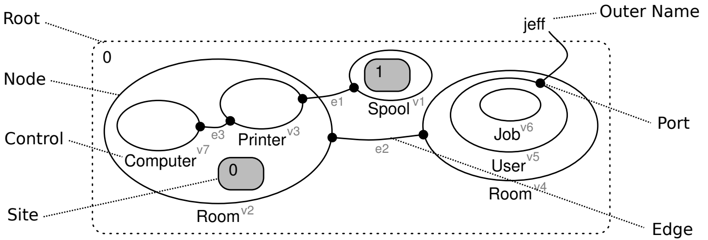
Bigraph Model of a Context-aware Printing System

- An office environment comprised of two rooms
- One room contains a computer and a printer
- The other room contains a user who holds a print job
- A user can submit the job for printing through the computer connected to the printer

Bigraph (visual syntax):



The Anatomy of Bigraphs



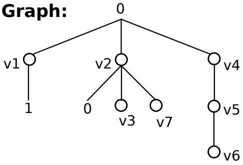
Place = Root or Node or Site

Link = Edge or Outer Name
Point = Port or Inner Name

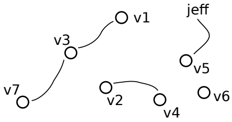
Signature:

{Job:0,
User:1,
Room:1,
Spool:1,
Printer:2,
Computer:1}

Place Graph:



Link Graph:



Graph-based Representation of EMOF Models

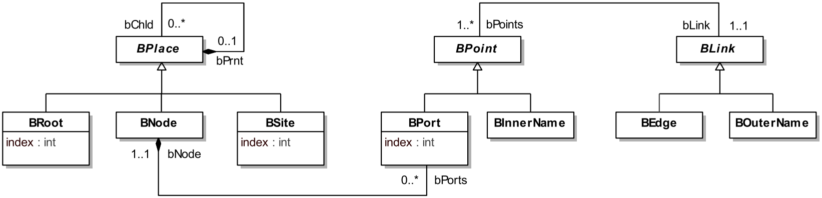
Natural formalization of object-oriented principles:

- Models as directed, unlabelled, typed graph (ASG)
- Types of nodes and edges are defined by a type graph (Meta-model); Special graph which includes the definition of
  - an inheritance hierarchy including abstract node types,
  - a containment structure,
  - opposite edges representing bidirectional edge types,
  - multiplicities attached to edge types.

Basic Type Graph Modeling the Anatomy of Bigraphs

Place graph structure

Link graph structure



Control-compatible Extension of the Basic Type Graph (w.r.t. a given bigraph signature)

General principle:

For each control defined by the signature, we introduce a corresponding subtype of the generic node type *BNode*.

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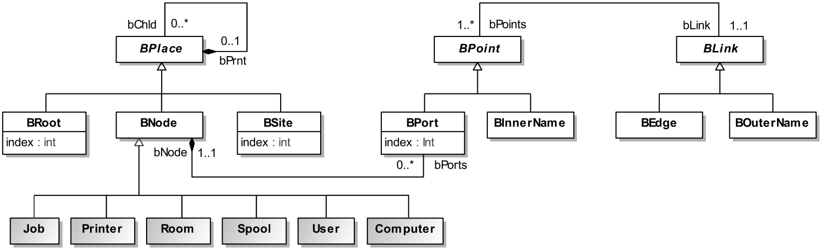

Handling of Arities defined by a Signature

Generic well-formedness rule:

For each subtype of *BNode*, restrict the multiplicity $[0..*]$ defined by the generic edge type *bPorts* to the fixed arity value.

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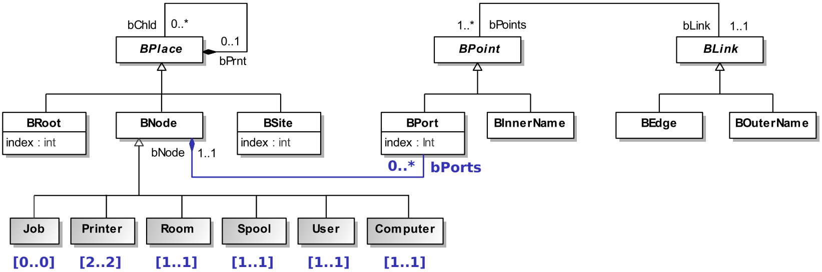


Mapping Bigraphs to Typed Graphs

Basic element mapping:

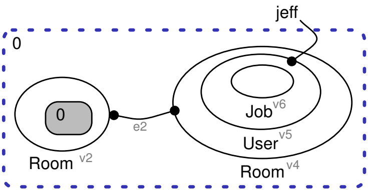
Bijectively map the elements of a bigraph B to the nodes of a typed graph G, with nodes in G properly typed.

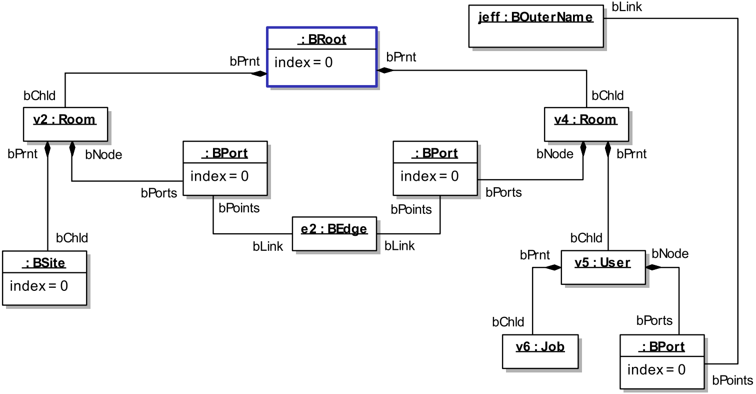
Additional soundness criteria:

Additional soundness criteria defined over the basic element mapping such that mapping induces a unique transformation from bigraphs to typed graphs (and vice versa).

Basic Element Mapping

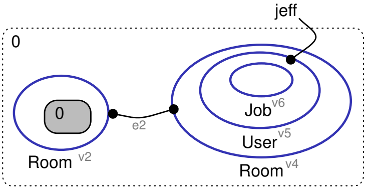
Mapping of bigraph roots

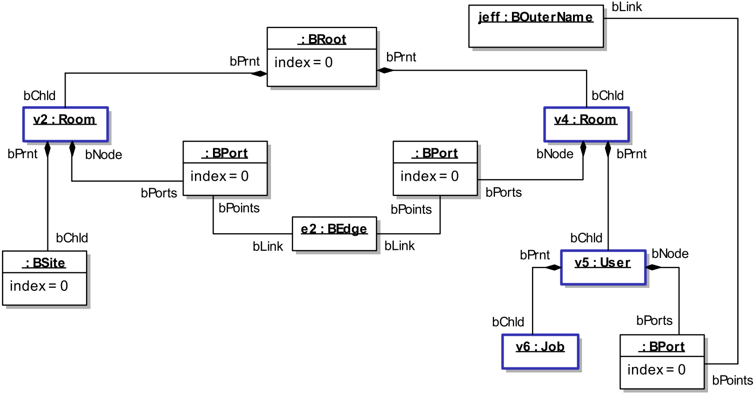




Basic Element Mapping

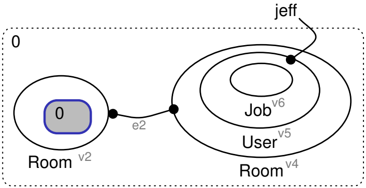
Mapping of bigraph nodes

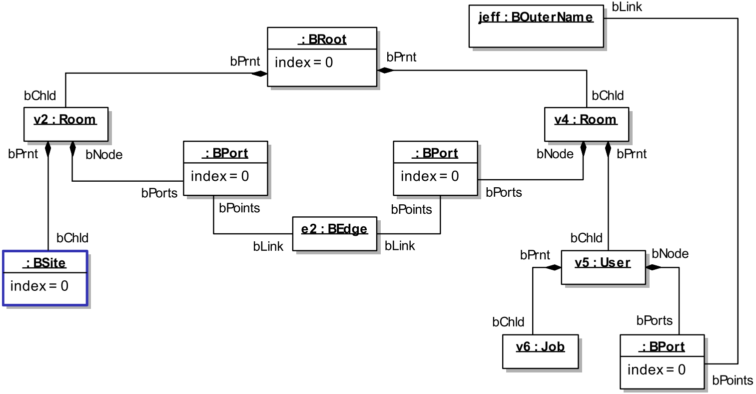




Basic Element Mapping

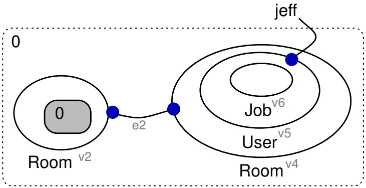
Mapping of sites

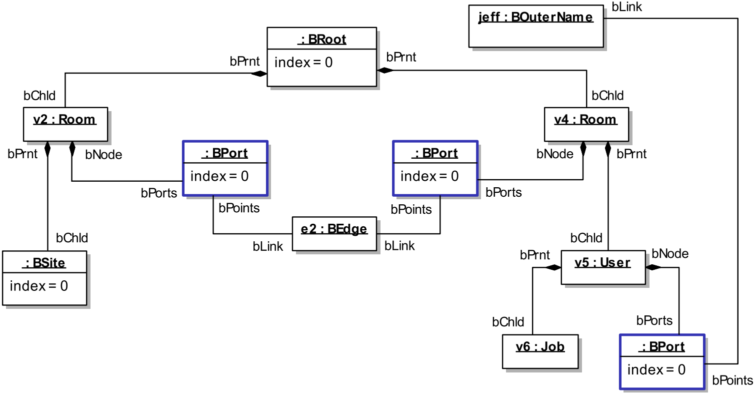




Basic Element Mapping

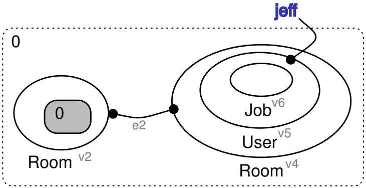
Mapping of ports

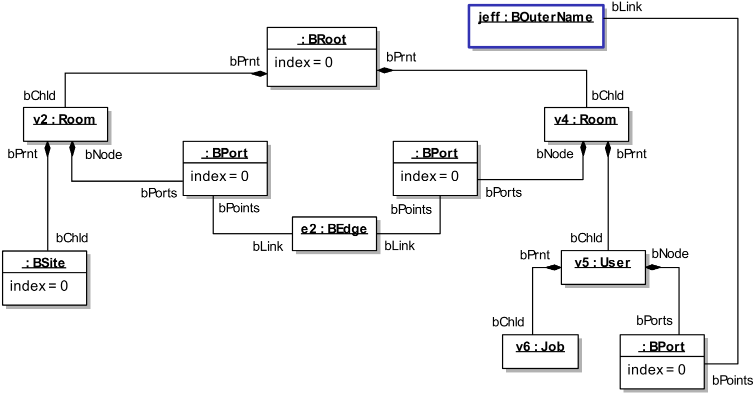




Basic Element Mapping

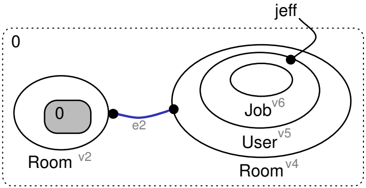
Mapping of names

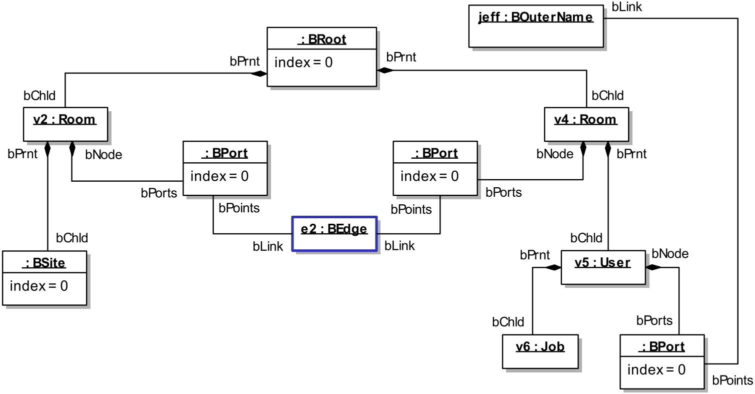




Basic Element Mapping

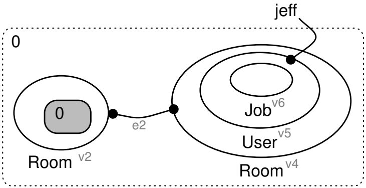
Mapping of bigraph edges

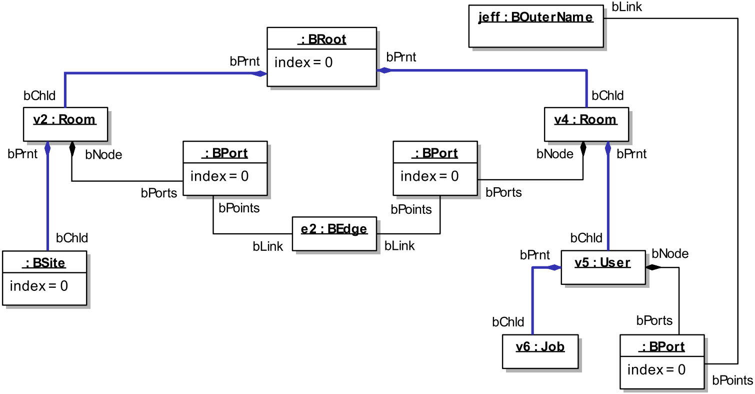




Additional Soundness Criteria

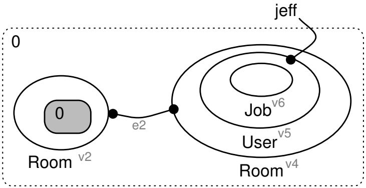
Nesting of places in B must coincide with the containment structure in G

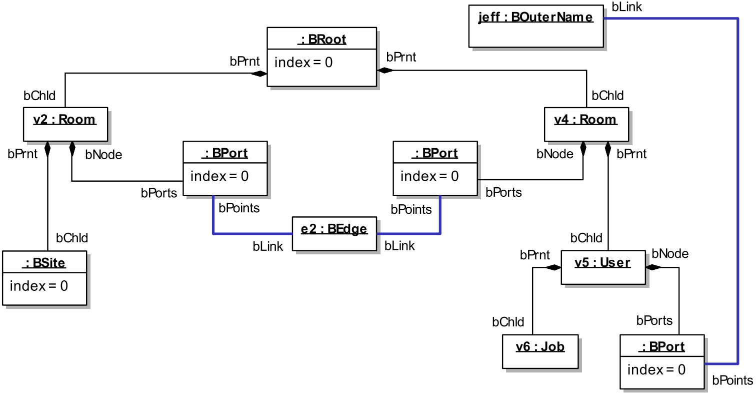




Additional Soundness Criteria

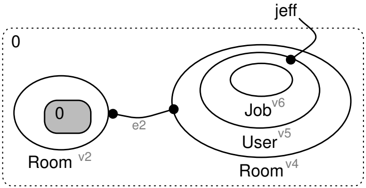
Linking structure in B must coincide with the linking structure in G

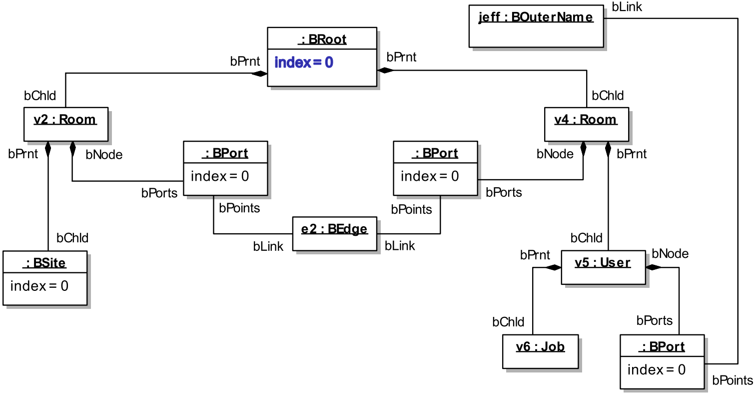




Additional Soundness Criteria

Indexing of roots in B must be consistent to indices in G





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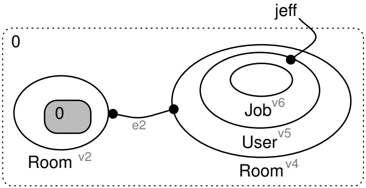
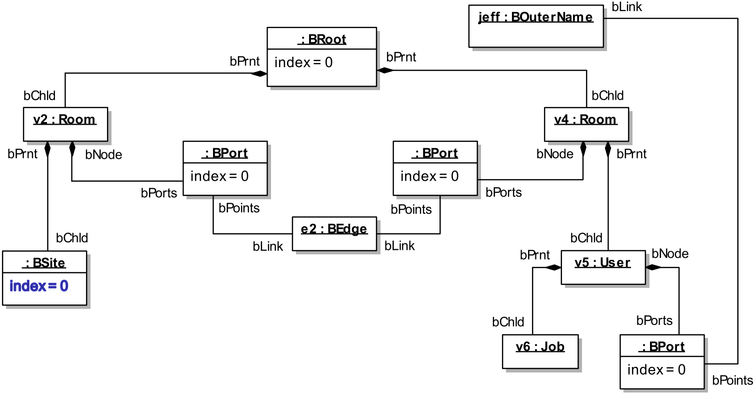
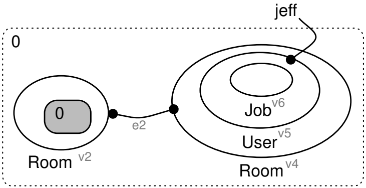
Indexing of sites in B must be consistent to indices in G

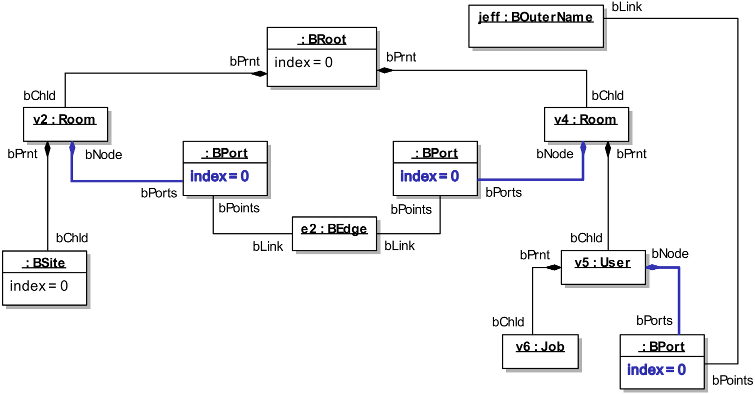




Additional Soundness Criteria

Indexing of ports in B must be consistent to ownership and indices in G

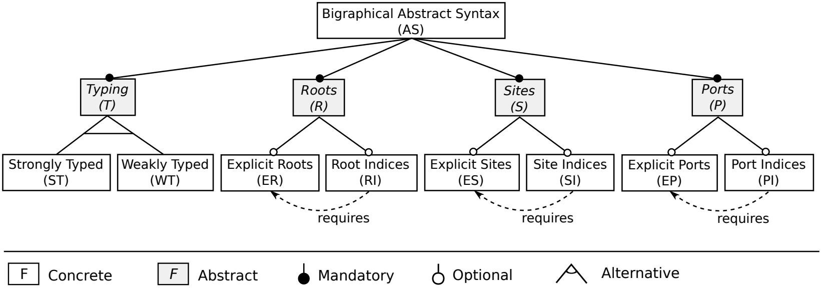




Application-Specific Variation Points

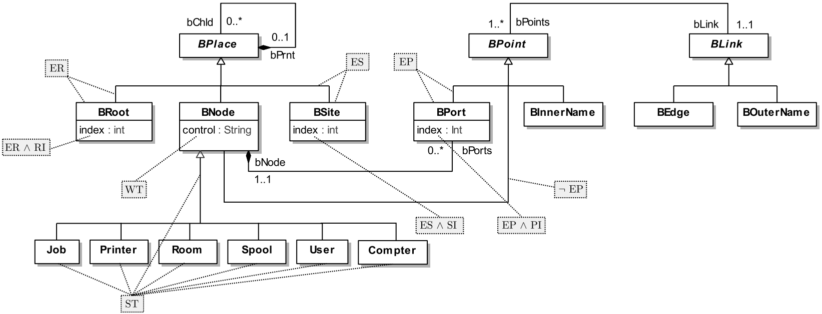
Definition of an appropriate abstract syntax depends on several design decisions, many of them being application-specific.

Variability model:



Implementing Type-level Variability

150% type graph:



Implementing Instance-level Variability

Delta-oriented approach:

- Core variant: canonical graph representation derived from a given bigraph
- Alternative variants: Obtained from the core variant by applying a set of deltas

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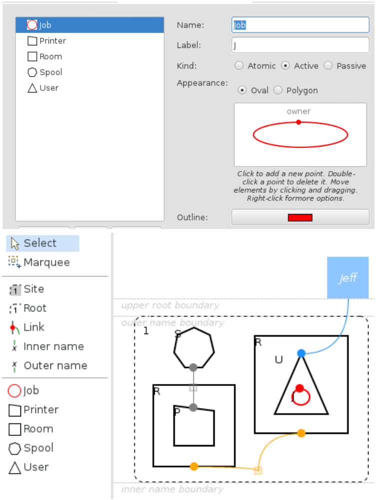
Example:

Delta $\Delta(ST, WT)$ to switch from the strongly typed variant to the the weakly typed one:

- Application condition: WT
- Specification: Each node representing a bigraphical node has to be retyped to the generic node type *BNode* and the value of the attribute *control* has to be set accordingly.

Tool Integration and Example Application

Bigraph modeling environment Big Red



Eclipse Modeling Framework (EMF)

Example application:

Additional constraint checking facility based on the OCL

Example invariant:

A Spool may only contain Jobs and Sites as nested places.

Specification in OCL:

context Spool
  inv:
    self.bChld−>forAll(c |
      c.oclIsTypeOf(BSite) **or**
      c.oclIsTypeOf(Job))

Future Work

Conceptually:

- Formalize the relation between bigraphical reactive systems and graph transformation systems
- Extension to other forms of bigraphs, e.g. bigraphs with sharing

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Technically:

- Provide a reference implementation based on Eclipse and EMF

Summary

Goals:

- Abstract syntax for bigraphs which is compliant with the EMOF standard defined by the OMG
- Facilitates:
  - Interoperability of bigraphical modeling and analysis tools
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Approach:

- Typed graphs as a formal underpinning of EMOF-based models
- Canonical mapping which maps bigraphs to typed graphs in a natural way
- Handling of application-specific variability using standard techniques from SPL engineering