Using Graph Rewriting Models for Object-Oriented Software Evolution

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Object-oriented software evolution

- Need better tool support for
  - version control
    - e.g. upgrading application frameworks
  - collaborative software development
    - e.g. software merging
  - evolution at a higher level of abstraction
    - e.g. refactoring
    - e.g. evolution of design pattern (instances)
  - change propagation, change impact analysis, effort estimation
  - ...

Tool support must be

- scalable
  - applicable to large-scale industrial software systems
    - “A major challenge for the research community is to develop a good theoretical understanding an underpinning for maintenance and evolution, which scales to industrial applications.” [Bennett&Rajlich 2000]
- generic
  - independent of the programming or modelling language
  - applicable in all phases of the software life-cycle
- formally founded
  - to prove that results are well-formed, correct, complete, confluent, compositional, ...

Graph rewriting

- can be used as formal model for software evolution

- graphs
  - compact and expressive representation of program structure and behaviour
  - 2-D nature removes redundancy in source code (e.g., localised naming)
- graph rewriting
  - intuitive description of transformation of complex graph-like structures
  - theoretical results help in the analysis of such structures
    - confluence property, parallel/sequential independence, critical pair analysis, compositionality, …

Two applications

- Software refactoring
  - use graph rewriting to express and detect various kinds of behaviour preservation
    - in collaboration with Prof. Serge Demeyer and Prof. Dirk Janssens, University of Antwerp
- Software merging
  - use graph rewriting to detect evolution/merge conflicts between parallel evolutions of the same software
    - PhD thesis of Tom Mens

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Application 1

Software Refactoring

What is refactoring?

- Refactorings are software transformations that restructure an object-oriented application while preserving its behaviour.
- According to Fowler (1999), refactoring
  - improves the design of software
  - makes software easier to understand
  - helps you find bugs
  - helps you program faster
- Formalisms can help to
  - gain insight in the fundamental underlying principles
  - prove correctness, e.g., to guarantee behaviour preservation

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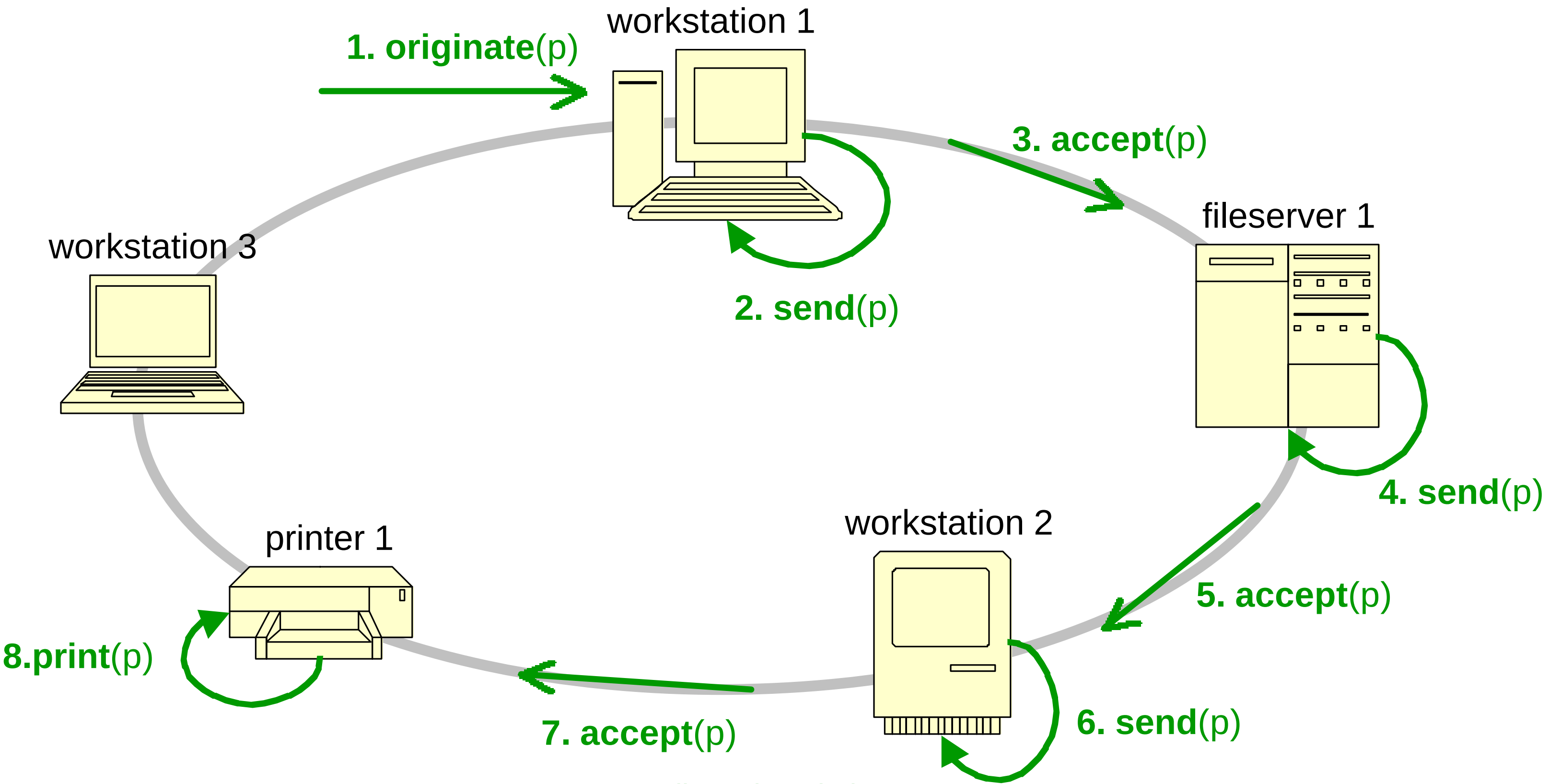
Refactoring case study: LAN

- Goal: show feasibility of graph rewriting formalism to express and detect various kinds of behaviour preservation



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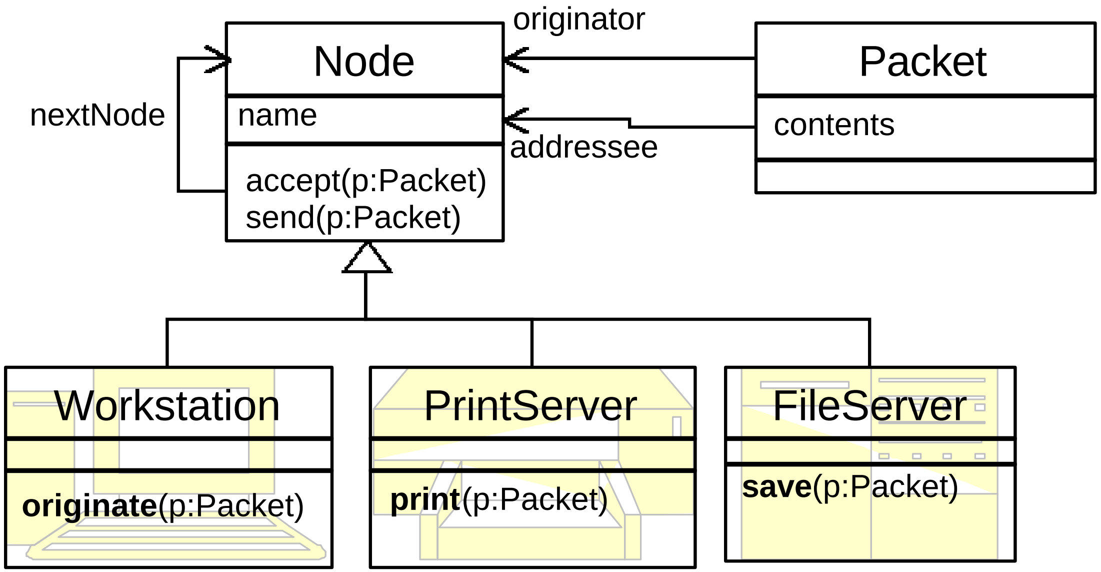
UML class diagram



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Java source code

```
public class Node {
  public String name;
  public Node nextNode;
  public void accept(Packet p) {
    this.send(p); }
  protected void send(Packet p) {
    System.out.println(
      name +
      "sends to" +
      nextNode.name);
    nextNode.accept(p); }
  }
```

```
public class Packet {
  public String contents;
  public Node originator;
  public Node addressee;
  }
```

```
public class Printserver extends Node {
  public void print(Packet p) {
    System.out.println(p.contents);
    }
  public void accept(Packet p) {
    if(p.addressee == this)
      this.print(p);
    else
      super.accept(p);
    }
  }
```

```
public class Workstation extends Node {
  public void originate(Packet p) {
    p.originator = this;
    this.send(p);
    }
  public void accept(Packet p) {
    if(p.originator == this)
      System.err.println("no
destination");
    else super.accept(p);
    }
  }
```

Refactoring Example 1: Encapsulate Field

Fowler 1999, page 206

There is a public field

Make it private and provide accessors

```
public class Node {
  public String name;
  public Node nextNode;
  public void accept(Packet p) {
    this.send(p); }
  protected void send(Packet p) {
    System.out.println(
      name +
      "sends to" +
      nextNode.name);
    nextNode.accept(p); }
  }
```

➡

```
public class Node {
  private String name;
  private Node nextNode;
  public String getName() {
    return this.name; }
  public void setName(String s) {
    this.name = s; }
  public Node getNextNode() {
    return this.nextNode; }
  public void setNextNode(Node n) {
    this.nextNode = n; }
  public void accept(Packet p) {
    this.send(p); }
  protected void send(Packet p) {
    System.out.println(
      this.getName() +
      "sends to" +
      this.getNextNode().getName());
    this.getNextNode().accept(p); }
}
```

Refactoring Example 2: Extract Method

Fowler 1999, page 110

You have a code fragment that can be grouped together

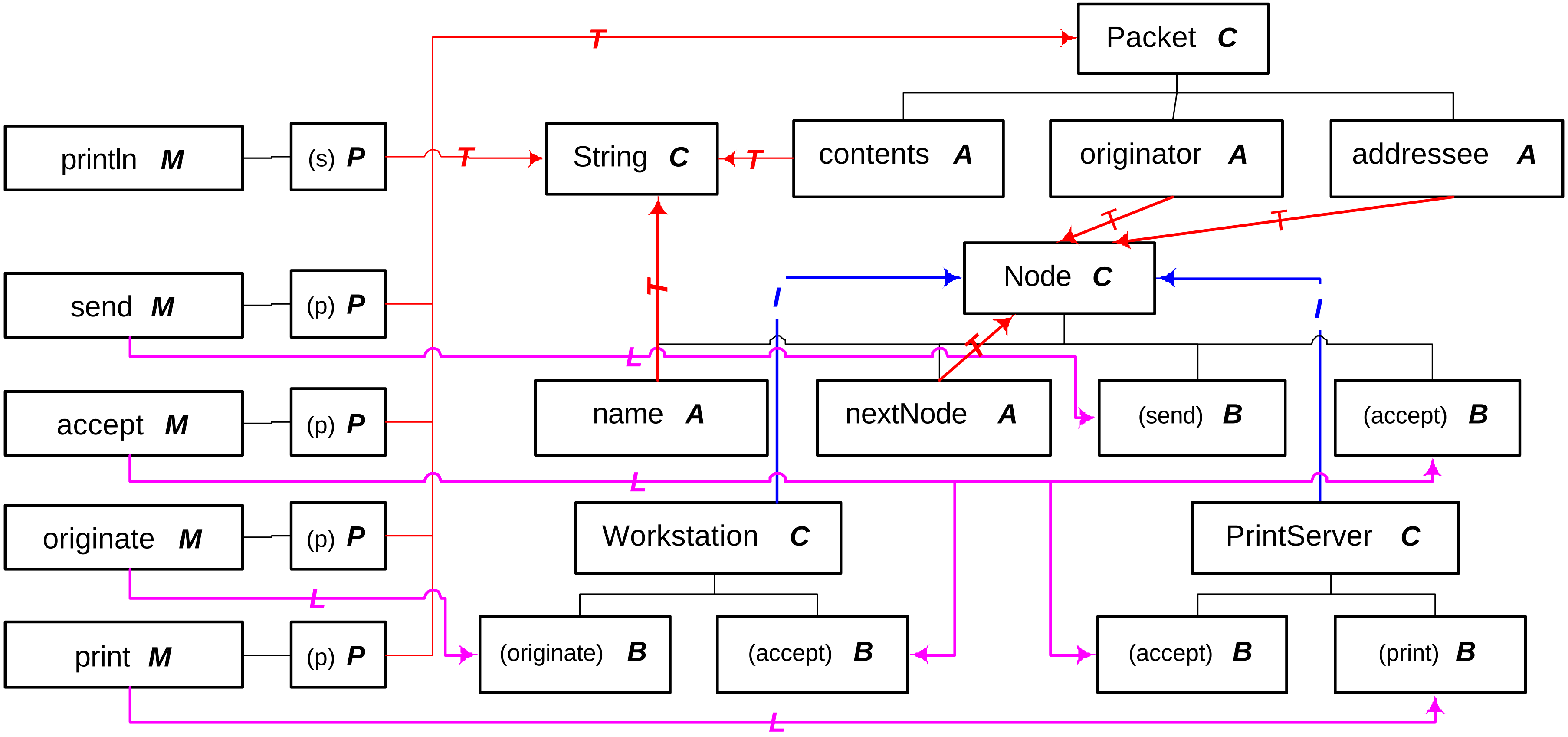
Turn the fragment into a method whose name explains the purpose of the method

```
public class Node {
  ...
  public void accept(Packet p) {
    this.send(p); }
  protected void send(Packet p) {
    System.out.println(
      this.getName() +
      "sends to" +
      this.getNextNode().getName());
    this.getNextNode().accept(p); }
  }
```

```
public class Node {
  ...
  public void accept(Packet p) {
    this.send(p); }
  protected void send(Packet p) {
    this.log(p);
    this.getNextNode().accept(p); }
  protected void log(Packet p) {
    System.out.println(
      this.getName() +
      "sends to" +
      this.getNextNode().getName()); }
  }
```

Graph representation – part 1

- program structure



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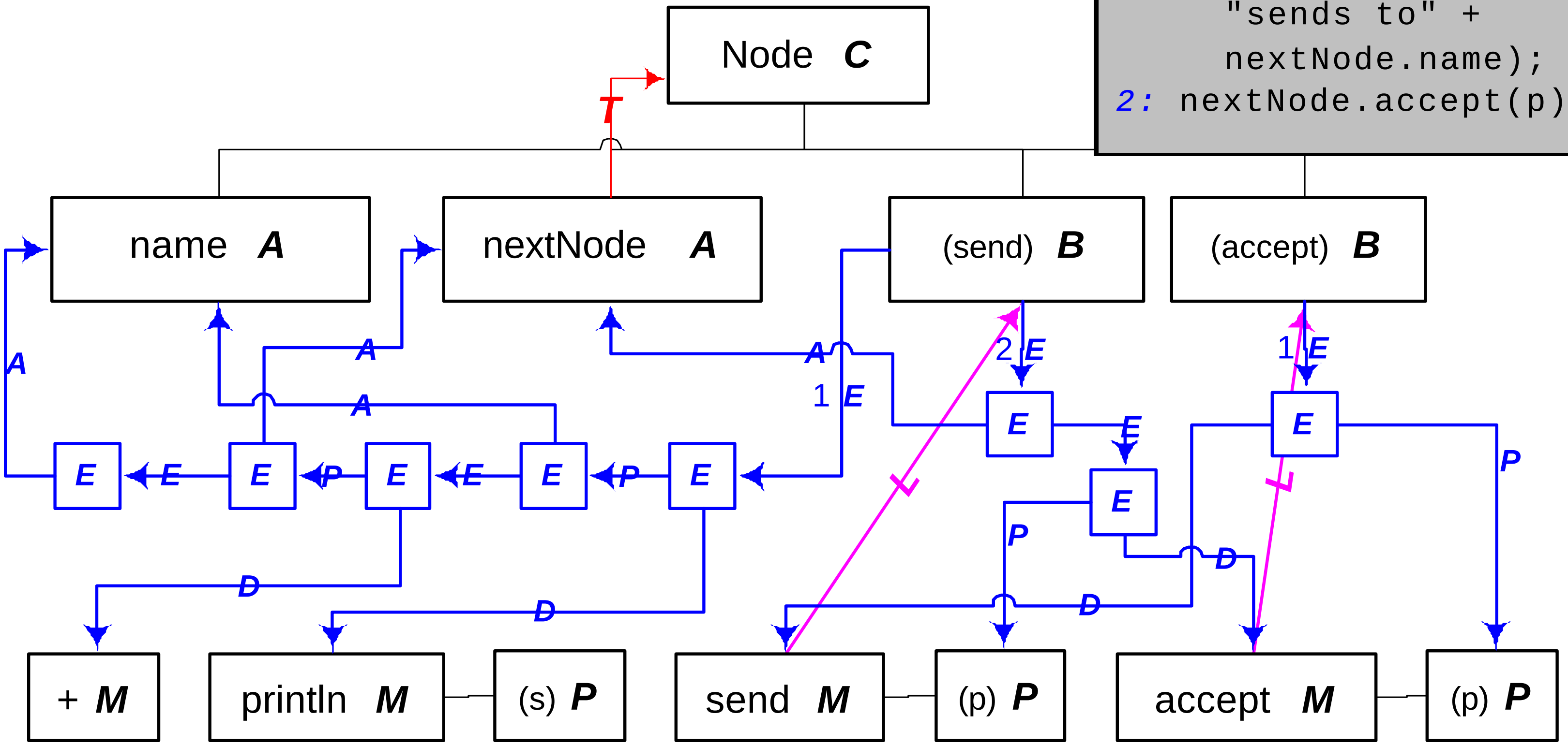
Graph representation – part 2

- program behaviour for class *Node*

```
void send(Packet p) {
1: System.out.println(
      name +
      "sends to" +
      nextNode.name);
2: nextNode.accept(p); }
```



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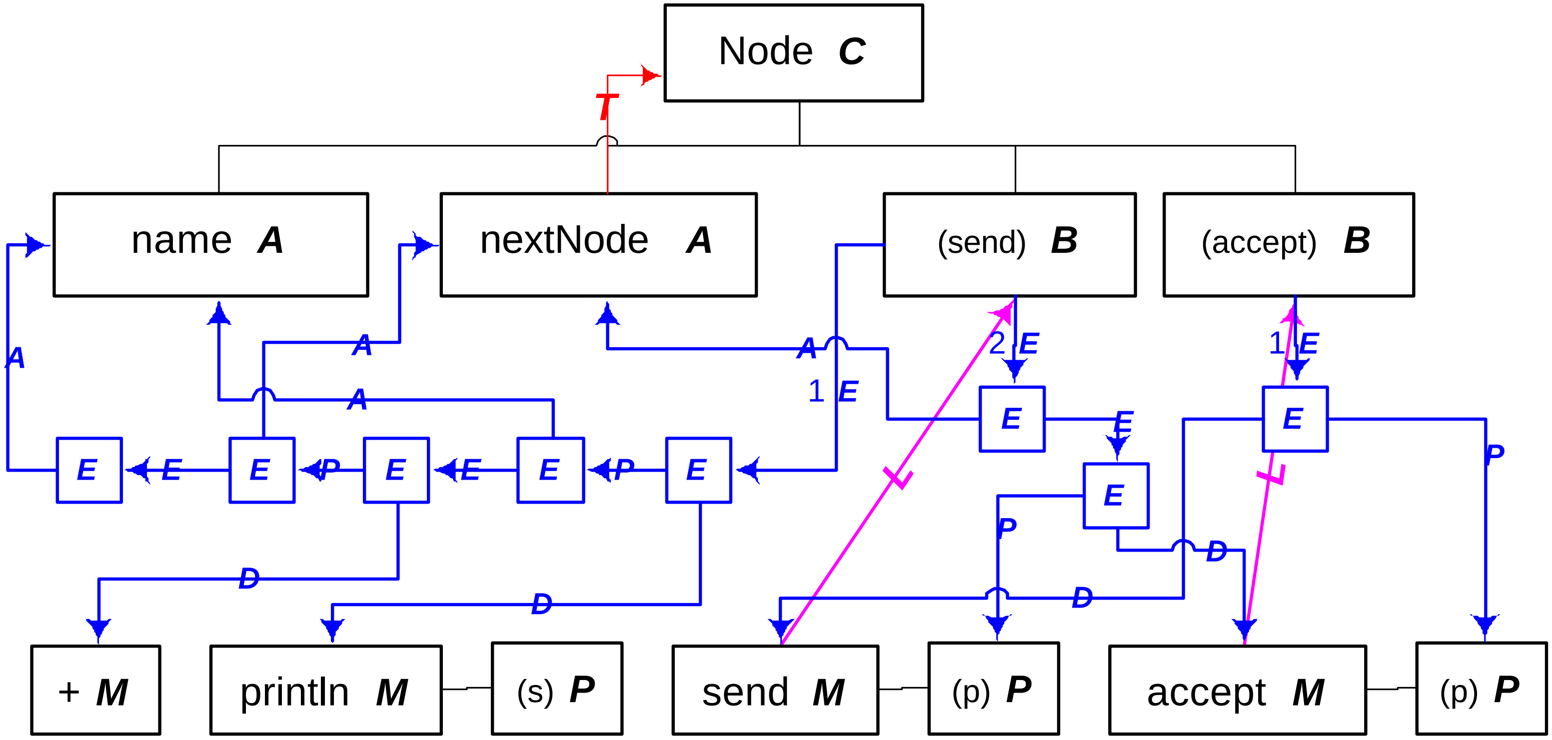
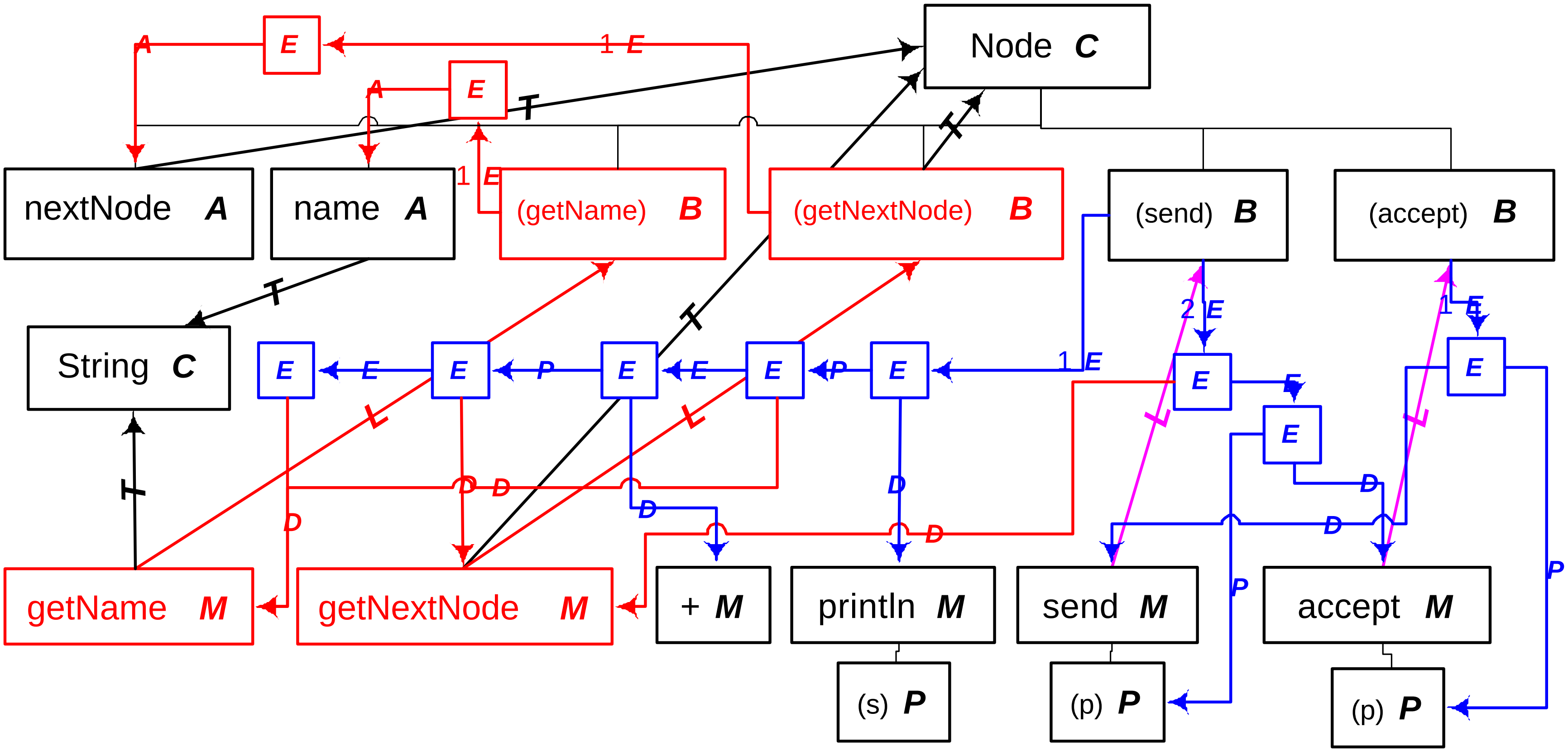
Refactoring Example 1: Encapsulate Field

- before the refactoring



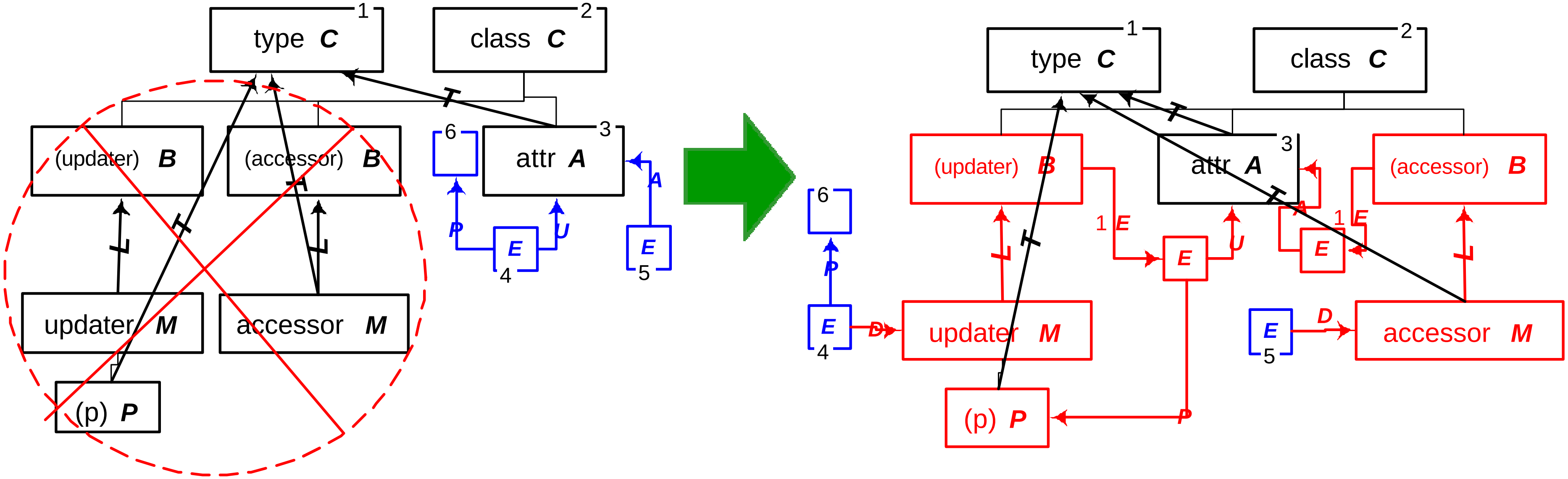
Refactoring Example 1: Encapsulate Field

- after the refactoring



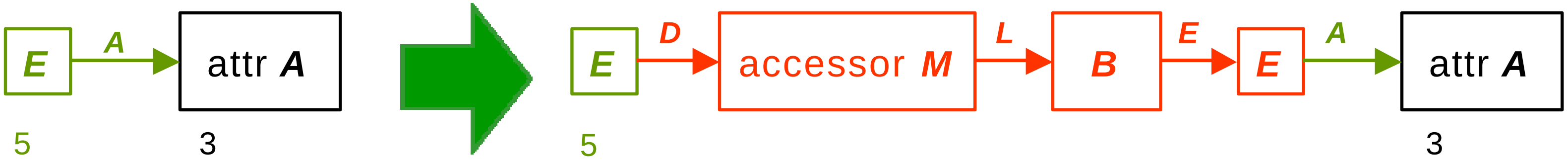
Refactoring Example 1: EncapsulateField graph production

- refactoring achieved by applying 2 occurrences of production *EncapsulateField(class,attr,type,accessor,updater)*
  - EncapsulateField(Node,name,String,getName,setName)
  - EncapsulateField(Node,nextNode,Node,getNextNode,setNextNode)



Refactoring Example 1: Behaviour preservation

- EncapsulateField preserves behaviour
  - *access preserving*: all attribute nodes can still be accessed via a transitive closure



  - *update preserving*: all attribute nodes can still be updated via a transitive closure

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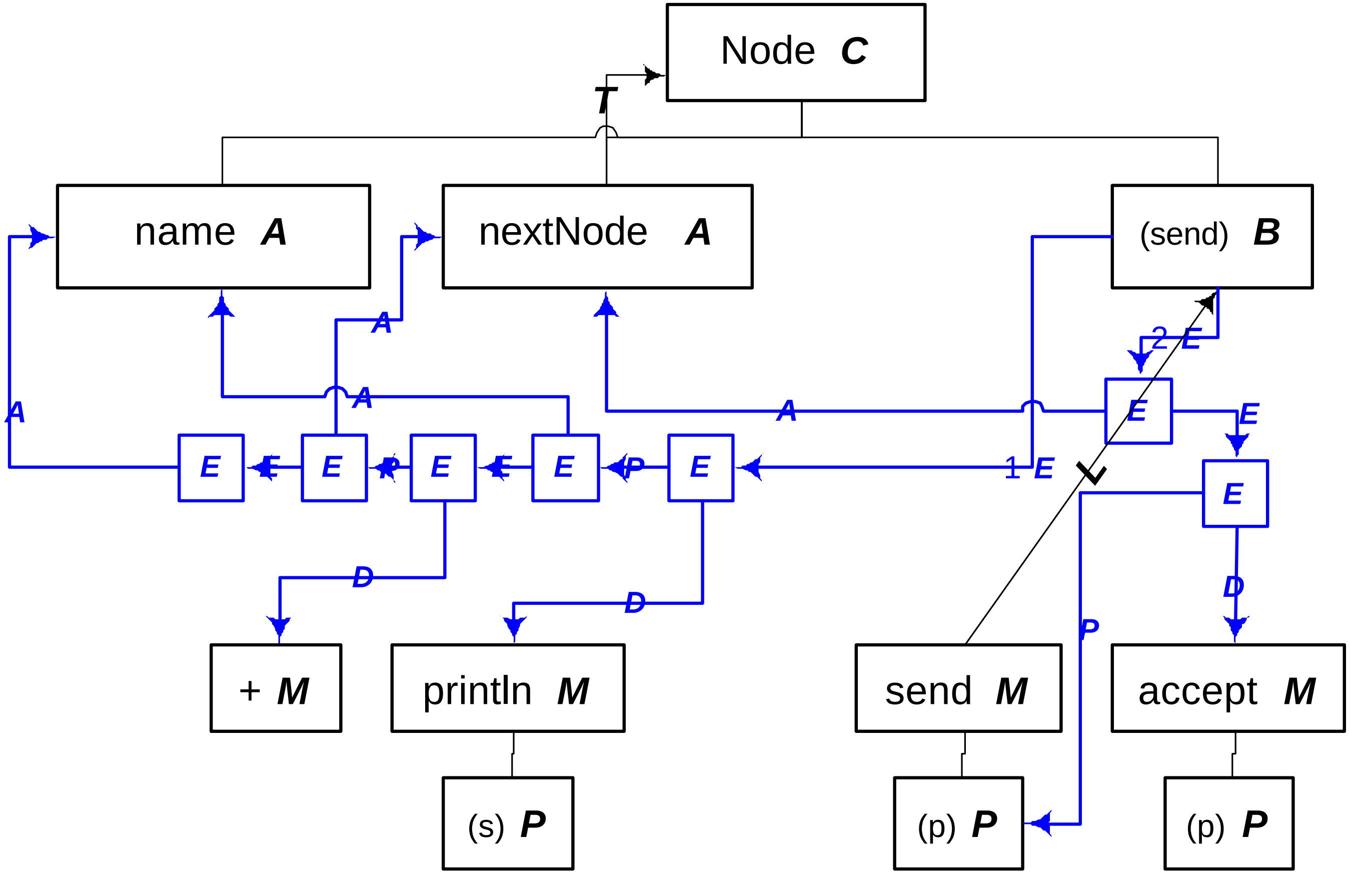
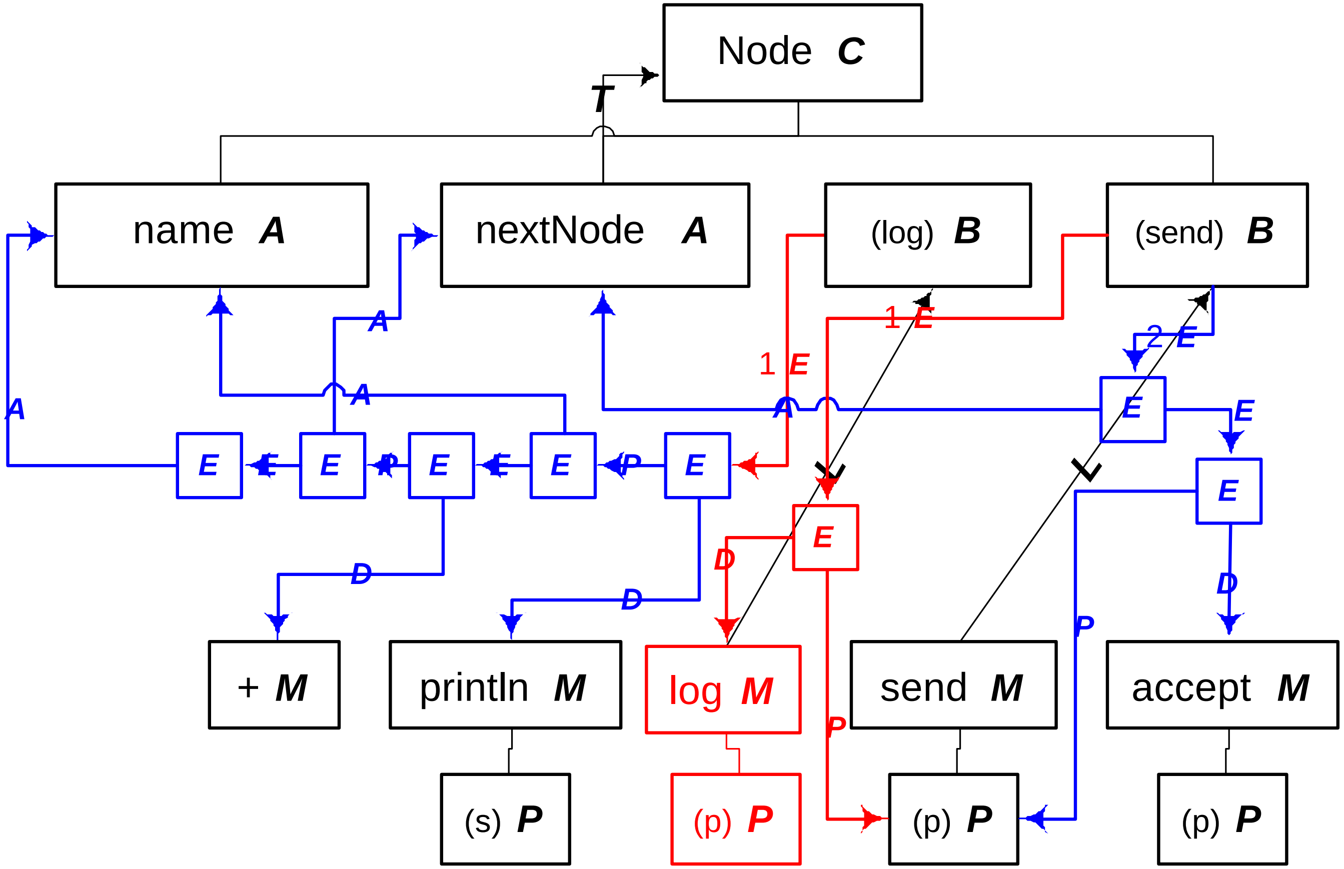
Refactoring Example 2: Extract Method

- ➢ before the refactoring ExtractMethod(Node,send,log,{1})



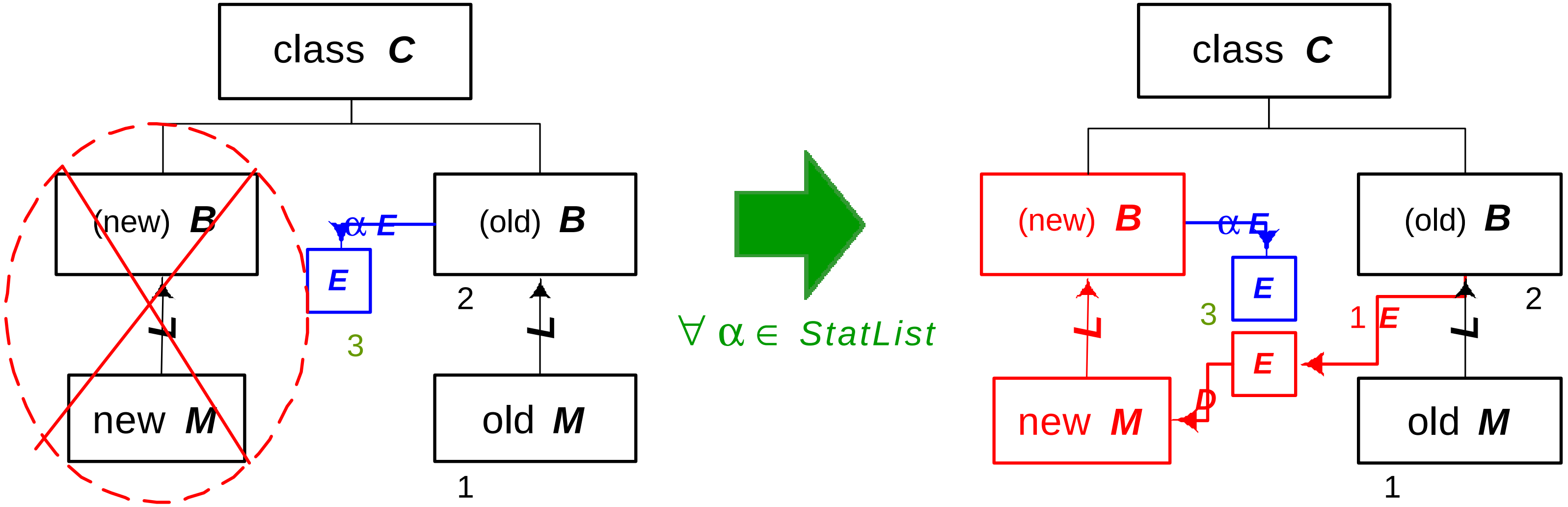
Refactoring Example 2: Extract Method

- after the refactoring ExtractMethod(Node,send,log,{1})



Refactoring Example 2: ExtractMethod graph production

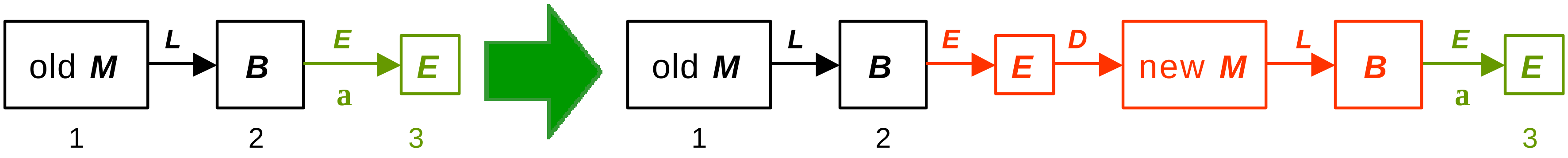
- refactoring is achieved by applying an occurrence of production ExtractMethod(*class*,*old*,*new*,*StatList*)
  - given the body of method *old* in *class*, redirect all statements in *StatList* to the body of a parameterless method *new*



(method parameters can be introduced afterwards by AddParameter)

Refactoring Example 2: Behaviour preservation

- ExtractMethod preserves behaviour
  - *statement preserving*: all expressions (calls, accesses, updates) that were performed before the refactoring, are still performed (via transitive closure) after the refactoring



∀ α ∈ *StatList*

Behaviour preservation types

- Access preservation (see EncapsulateField)
  - each method body (indirectly) performs at least the same attribute accesses as it did before the refactoring
- Update preservation (see EncapsulateField)
  - each method body (indirectly) performs at least the same attribute updates as it did before the refactoring
- Statement preservation (see ExtractMethod)
  - each method body (indirectly) performs at least the same statements as …
- Call preservation
  - each method body (indirectly) performs at least the same method calls as …
- Type preservation
  - each statement in each method body still has the same result type or return type as …

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Refactoring: Conclusion

- Graph rewriting seems a useful and promising formalism to provide support for refactoring
  - More practical validation needed
  - Current experiment only focuses on behaviour preservation
  - A formalism can assist the refactoring process in many other ways

  - Proposed FWO research project (4 years / 3 persons)

Refactoring: Open questions

- Which program properties should be preserved by refactorings?
    - input/output behaviour, timing constraints, static versus dynamic behaviour
    - support for non-behaviour-preserving refactorings?
- What is the complexity of a refactoring?
    - complexity of applicability / complexity of applying the refactoring
- How do refactorings affect quality factors?
    - increase/decrease complexity, understandability, maintainability, …
- How can refactorings be composed/decomposed?
    - composite refactorings / extracting refactorings from successive releases
- How do refactorings interact?
    - parallel application of refactorings may lead to consistency problems
- How do refactorings affect design models?
- Language-independent formalism for refactoring?

Application 2

Software
Merging

What is Software Merging?

- Context: Collaborative Software Development
  - many software developers working together on the same software
  - need to integrate parallel changes made to the same code
- Software merging
  - automated tool support for integrating these parallel changes
  - detect inconsistencies (conflicts) between parallel changes
  - provide support for resolving these inconsistencies

  - Merge tools are usually part of a configuration management system or version management system
    - e.g. CVS, RCS, ClearCase, Adele, …

Problem

```
public class Node {
  public String name;
  public Node nextNode;
  public void accept(Packet p) {
    this.send(p); }
  protected void send(Packet p) {
    System.out.println( name +
      "sends to" + nextNode.name);
    nextNode.accept(p); }
  }
```

Encapsulate Field

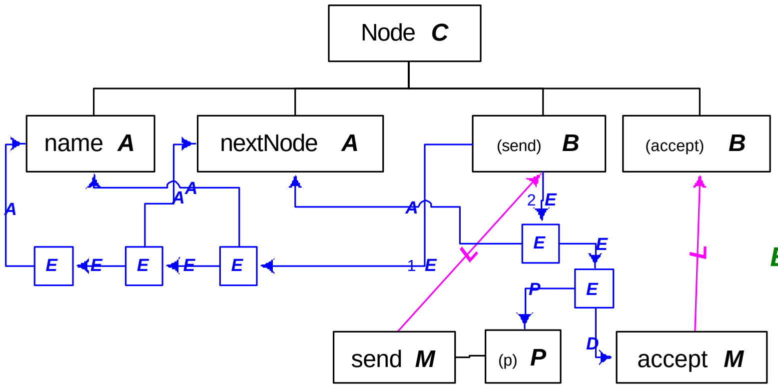
```
public class Node {
  private String name;
  private Node nextNode;
  public String getName() {return this.name;}
  public void setName(String s) {this.name=s;}
  public Node getNextNode() {
    return this.nextNode; }
  public void setNextNode(Node n) {
    this.nextNode = n; }
  public void accept(Packet p) {this.send(p);}
  protected void send(Packet p) {
    System.out.println(this.getName() +
      "send to" + this.getNextNode().getName());
    this.getNextNode().accept(p); }
  }
```

Extract Method

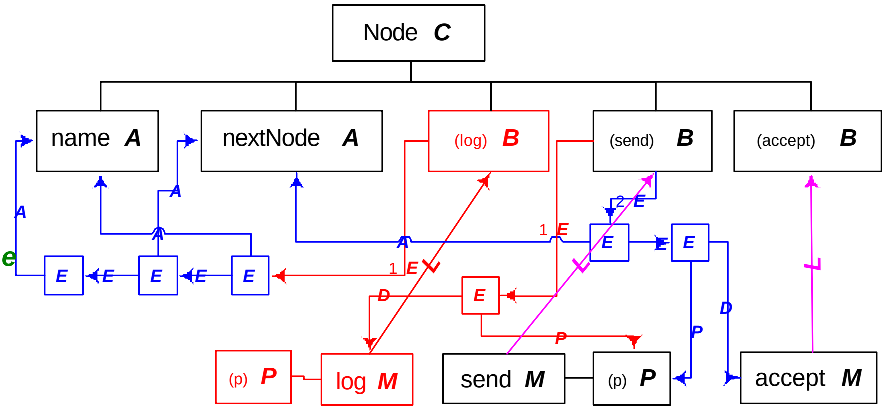
```
public class Node {
  ...
  public void accept(Packet p) {
    this.send(p); }
  protected void send(Packet p) {
    this.log(p);
    this.nextNode().accept(p); }
  protected void log(Packet p) {
    System.out.println( name +
      "sends to" + nextNode.name); }
  }
```

Current merge tools cannot merge the two parallel changes automatically due to a merge conflict in the **send** method

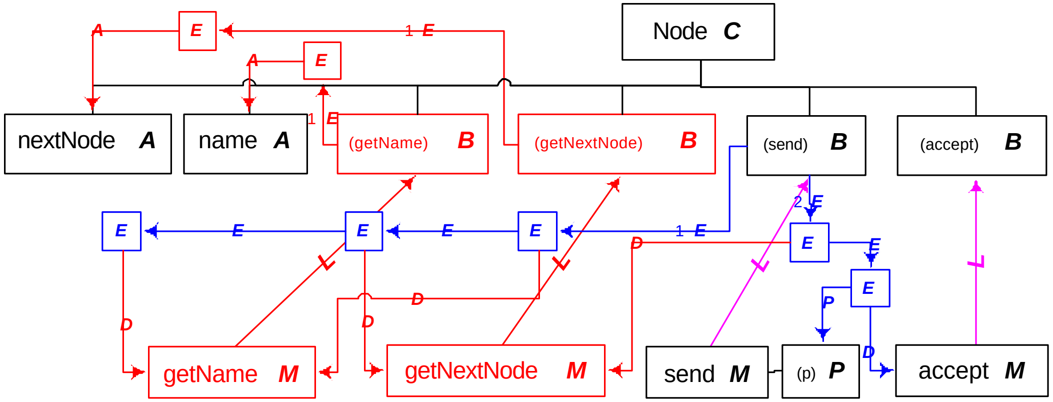
Solution



Encapsulate Field



Extract Method



Sequential application of the parallel graph rewritings yields correct merge result

Solution

- Express and document software evolution by means of explicit graph transformations
  - Detect whether parallel evolutions can be sequentialised

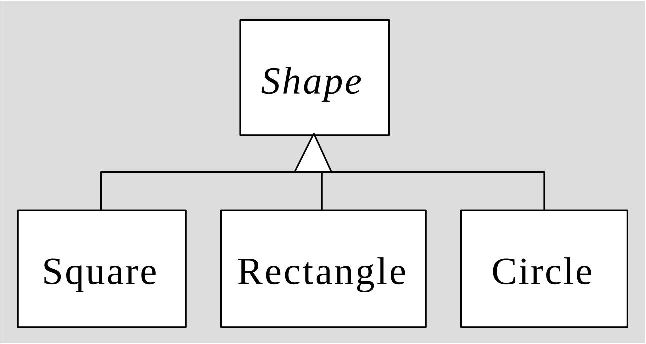
    (parallel/sequential independence)
  - If not, syntactic conflicts need to be resolved first
    - e.g. renaming same entity twice
  - If yes, merging corresponds to sequential application of graph transformations
    - Order of application is irrelevant (confluence property)
    - Potential semantic conflicts need to be detected

      (based on category-theoretical notion of pushouts/pullbacks)

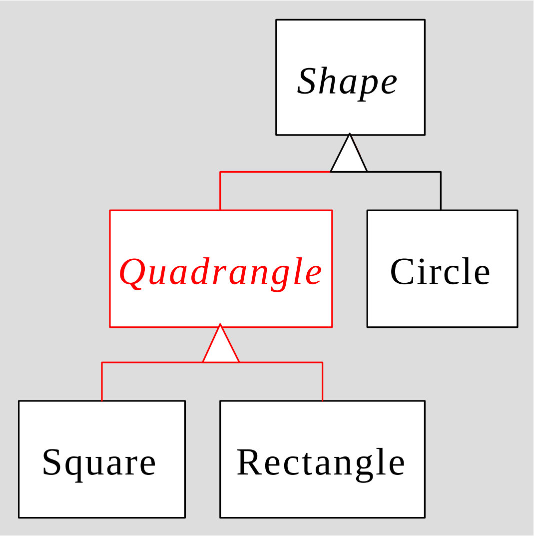
For more details…

- see
  - *A formal foundation for object-oriented software evolution*
    - Tom Mens. PhD Thesis, Vrije Universiteit Brussel, September 1999
    - Extended abstract in Proc. Int. Conf. Software Maintenance 2001, pp. 549-552, IEEE Computer Society Press
  - *Conditional graph rewriting as a domain-independent formalism for software evolution*
    - Tom Mens. Proc. Agtive '99, Lecture Notes in Computer Science 1779: 127-143, Springer-Verlag, 2000
  - *A state-of-the-art survey on software merging*
    - Tom Mens. IEEE Trans. Software Engineering, 28(5), May 2002

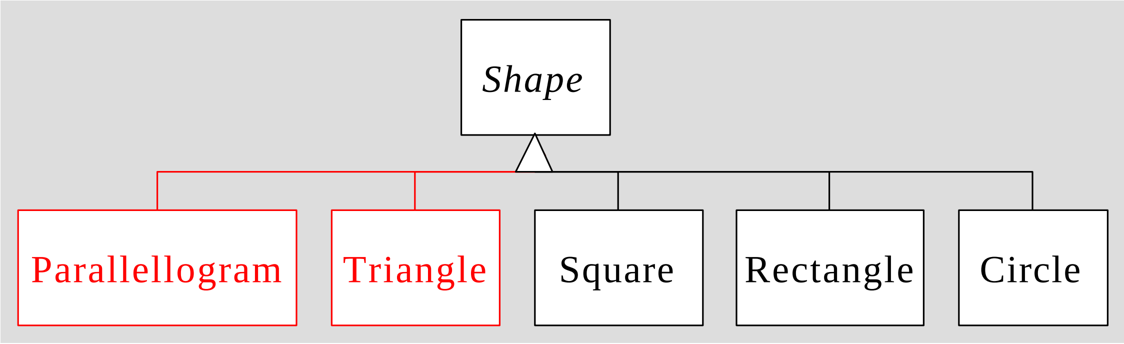
Open Issue: Structural Conflicts



InsertClass
(Shape,Quadrangle,
[Square,Rectangle])



AddSubclass(Shape,Parallellogram)
AddSubclass(Shape,Triangle)



More difficult to detect in a general way

General Conclusion

- Graph rewriting can be used as a formal model for various aspects of software evolution
  - software refactoring
  - software merging
  - …
- Formalism allows us to express interesting properties
  - Behaviour preservation of refactorings
  - Compositionality of refactorings
  - Syntactic and semantic merge conflicts
- More theoretical research and practical validation needed
  - Proposed FWO research project (4 years / 3 persons)
  - Apply formalism on evolution of real software systems