Tutorial Introduction to Graph Transformation

A software engineering perspective

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Why it is fun: Programming By Example

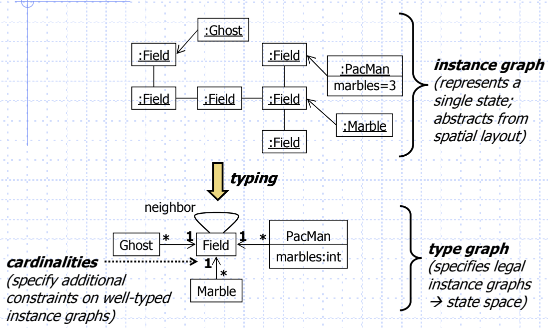
StageCast (www.stagecast.com): a visual programming environment for kids (from 8 years on), based on

- behavioral rules associated to graphical objects
- visual pattern matching
- simple control structures (priorities, sequence, choice, ...)
- external keyboard control

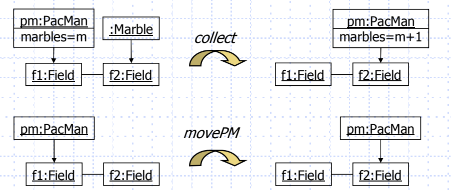
→ intuitive rule-based behavior modelling

Next: abstract from concrete visual presentation

States of the PacMan Game: Graph-Based Presentation

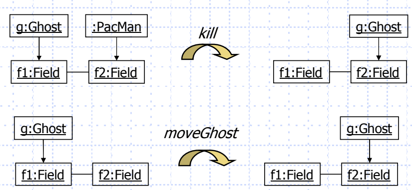


Rules of the PacMan Game: Graph-Based Presentation, PacMan



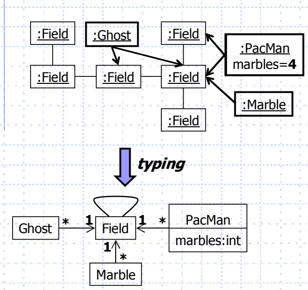
PacMan's rules:
collect has priority over *movePM*

Rules of the PacMan Game: Graph-Based Presentation, Ghost



Ghost's rules:
kill has priority over *moveGhost*

Graph Transformation



collect ;
kill

Foundations of Graph Transformation

How it works.

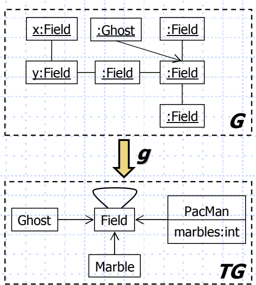
Outline

- A Basic Formalism
  - Light-weight presentation of a categorical approach.
- Variations and Extensions
  - Syntactic and semantic alternatives, and advanced features.
- Where it Comes From
  - Roots and inspiration

How it works: Typed Graphs

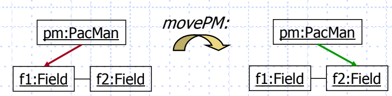
- Directed graphs as algebraic structures $G = (V, E, src, tar)$ with $src, tar: E \rightarrow V$
- Graph homomorphism as pair of mappings $h = (h_V, h_E): G_1 \rightarrow G_2$ with
  - $h_V: V_1 \rightarrow V_2$
  - $h_E: E_1 \rightarrow E_2$

  preserving *src* and *tar*
- Typed graphs given by
  - fixed type graph *TG*
  - instance graphs *G* typed over *TG* by homomorphism $g: G \rightarrow TG$



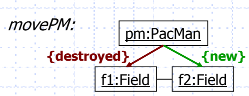
Rules

- $p: L \rightarrow R$ with $L \cap R$ well-defined, in different presentations
  - like above (cf. PacMan example)
  - with $L \cap R$ explicit [DPO]: $L \leftarrow K \rightarrow R$

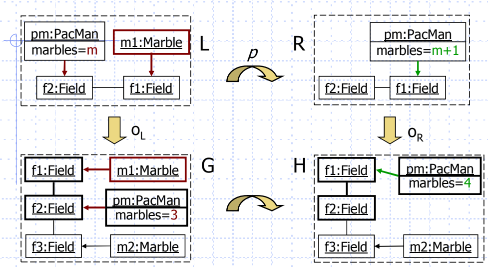


Rules

- $p: L \rightarrow R$ with $L \cap R$ well-defined, in different presentations
  - like above (cf. PacMan example)
  - with $L \cap R$ explicit [DPO]: $L \leftarrow K \rightarrow R$
  - with L, R integrated [UML]: $L \cup R$ and marking
    - $L - R$ as {destroyed}
    - $R - L$ as {new}

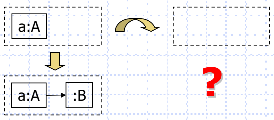


Transformation Step: Operational



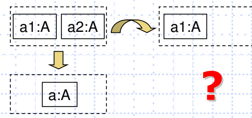
1. select rule $p : L \rightarrow R$; occurrence $o_L : L \rightarrow G$
2. remove from G the occurrence of $L \setminus R$
3. add to result a copy of $R \setminus L$

Semantic Questions: Dangling Edges



- conservative solution: application is forbidden
  - invertible transformations, no side-effects
- radical solution: *delete dangling edges*
  - more complex behavior, requires explicit control

Semantic Questions: Conflicts



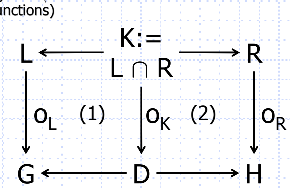
- conservative solution: application is forbidden
  - invertible transformations, no side-effects
- radical solution: *give priority to deletion*
  - more complex behavior, requires explicit control

Transformation Step: Declaratively

Set-theoretic: Assume G and H with $G \cap H$ well-defined.
Then, $G \Rightarrow_{p(o_L)} H$ **iff** there exists a homomorphism $o: L \cup R \to G \cup H$
such that
- $o(L) \subseteq G$ and $o(R) \subseteq H$
- $o(L \setminus R) = G \setminus H$ and $o(R \setminus L) = H \setminus G$
(on the underlying sets and functions)

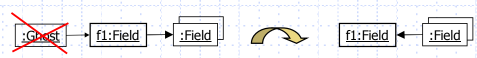
Category-theoretic: $G \Rightarrow_{p(o_L)} H$
iff (1) and (2) are pushouts

→ conservative solution
(DPO, Ehrig et al 73)



Advanced Features

Dealing with unknown context
- set-nodes (multi-objects): match all nodes with the required connections
- explicit (negative) context conditions



(turns f1 into a trap by reversing all outgoing edges to Field vertices, but only if there is no Ghost)

Control
- priorities: ***movePM*** only if ***collect*** is not possible
- programmed transformation: IF NOT ***collect*** THEN ***movePm***;

Where it comes from …

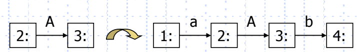
Chomsky Grammars | **Term Rewriting** | **Petri Nets**

↓ ↓ ↓

Graph Transformation and Graph Grammars

Chomsky Grammars: Rewriting of Strings

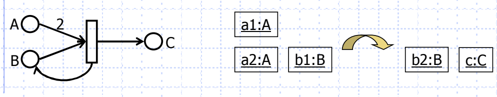
Production **A → aAb** as (context-free: one vertex or edge in *L*) graphical production rule



- Theory of *graph grammars* as formal language theory for graphs
  - hierarchies of language classes and grammars
  - decidability and complexity results
  - parsing algorithms

Petri Nets: Rewriting of Multisets

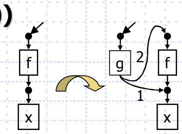
A PT net transition as graph transformation rule



- Theory of concurrency for graph transformation
  - independence, causality, and conflicts
  - processes, unfoldings
  - analysis techniques

Term Rewriting: Rewriting of Trees or DAGs

TR Rule **f(x) → g(x, f(x))** as DAG rewrite rule



- Theory of term graph rewriting
  - soundness and completeness of TGR w.r.t. TR
  - termination, critical pairs, and confluence

Applications of Graph Transformation

What it is all good for (except video games).

Where it comes from and what it is good for

Chomsky Grammars	Term Rewriting	Petri Nets
↓	↓	↓

Graph Transformation and Graph Grammars

↓	↓	↓
Diagram Languages	Models of Computation	Behaviour Modelling and Visual Programming

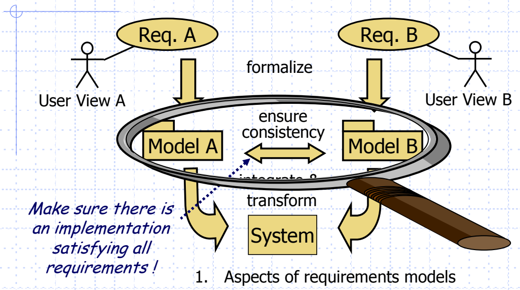
Applications of Graph Transformation

Behaviour modelling: conflicts and dependencies in functional requirements

Model of computation: the rules of service-oriented architectures

Diagram languages: the "complete" definition of visual languages

Software Development as Integration of Views



1. Aspects of requirements models
2. Conflicts between functional requirements
3. From conflicts to (in)consistency

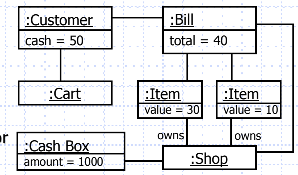
1. Aspects of Requirements Models

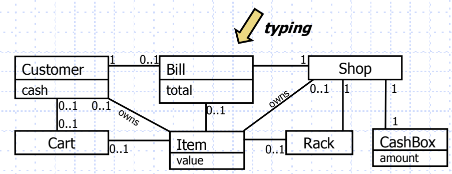
Model A | Model B

1. Domain model: Agree on vocabulary first !
   - → class and object diagrams
2. Business process model: Which actions are performed in which order ?
   - → use case description in natural language
   - → activity diagrams

Structure: Class and Object Diagrams

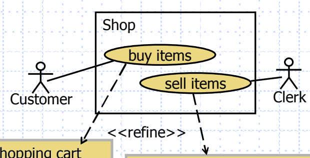
- ✓ formal, e.g., attributed graphs at the type and instance level
- ✓ established techniques for view integration





Behaviour: Use Case Description by Structured Text

- ✓ based on vocabulary of integrated domain model



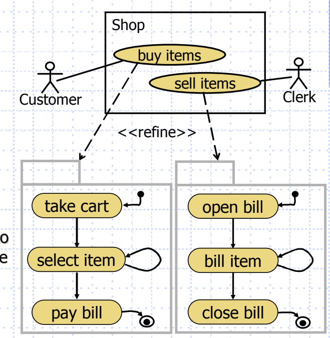
- ✖ take shopping cart
- ✖ select items from rack
- ✖ take items out of cart
- ✖ pay required amount
- ✖ collect items

- ✖ create empty bill for new customer
- ✖ take items out of customer's cart
- ✖ add them to the bill
- ✖ collect payment
- ✖ pack and give items to customer

- ✖ no way to tell if views are consistent

Behaviour: Activity Diagrams

- ✓ identifies actions and their ordering
- ✖ no formal integration with structural model
- ✖ still no indication as to whether the views are consistent



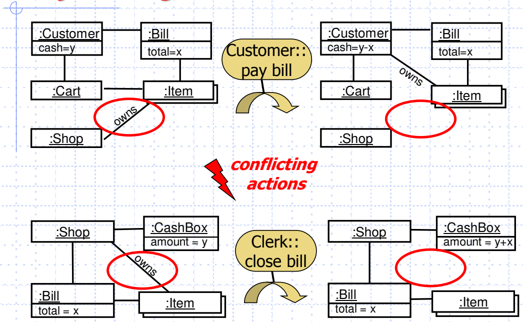
1. Aspects of Requirements Models

Model A | Model B

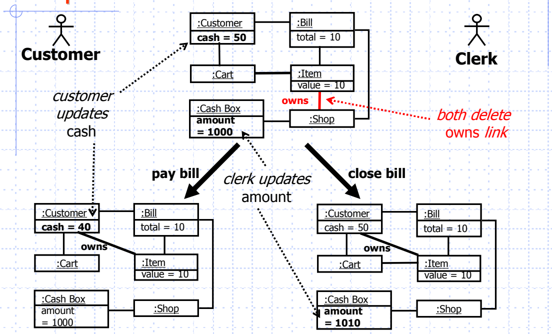
- ✓ Domain model: Agree on vocabulary first !
  - → class and object diagrams
- ✓ Business process model: Which actions are performed in which order ?
  - → use case description in natural language
  - → activity diagrams

3. Functional model: What happens if an action is performed ?
   - → pre-/post conditions as logic constraints
   - → transformation rules on object diagrams (Fusion, Catalysis, Fujaba, formally: graph transformations)

Function: Transformation Rules on Object Diagrams

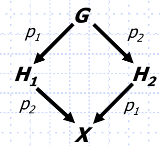


2. Conflicts Between Functional Requirements



Independence, Causality and Conflicts in Graph Transformation: Outline

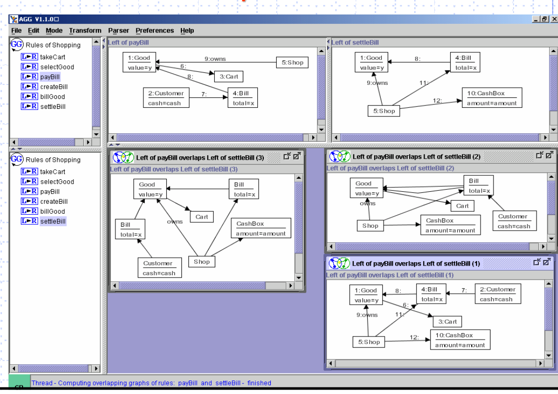
1. Alternative steps are *parallel independent* if they do not disable each other. Otherwise they are *in conflict*.
2. Consecutive steps are *sequentially independent* if they may be swapped without affecting the result. Otherwise they are *causally dependent*.



Characterization: Two (alternative or consecutive) steps are independent **iff** all commonly accessed items are in read-access only.

Problem: Find *potential* conflicts and causal dependencies between *rules* statically (at development time)

Critical Pair Analysis with AGG



Summary

- Specification of actions by means of transformation rules on object diagrams
  - precise, yet visual and intuitive
  - integrates structural and behavioral aspect
- Graph transformation background
  - allows formal analysis of conflicts and causal dependencies
  - combined with domain knowledge this reveals potential inconsistencies between views
- Scalability
  - how to live with the computational complexity of critical pair analysis
  - how to organize and filter large amounts of analysis data

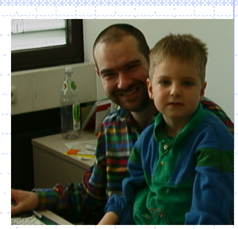
Applications of Graph Transformation

Behaviour modelling: conflicts and dependencies in functional requirements

Model of computation: the rules of service-oriented architectures

Diagram languages: the "complete" definition of visual languages

Application Scenario: Shopping with Max

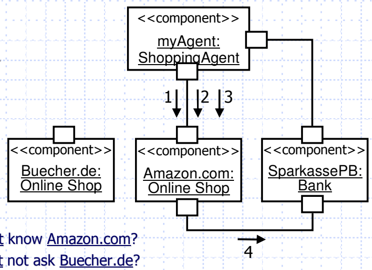


Looking for the most recent *Harry Potter*, we employ a *Shopping Agent* to

- find a book shop
- obtain further info: availability, payment methods, …
- choose the best offer
- order and pay via bank transfer

As component-based system (CBS)

1: get product info
2: place order
3: pay bill
4: request transfer

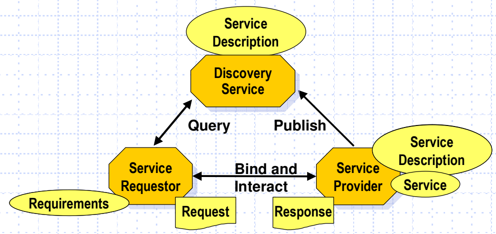


But, ...

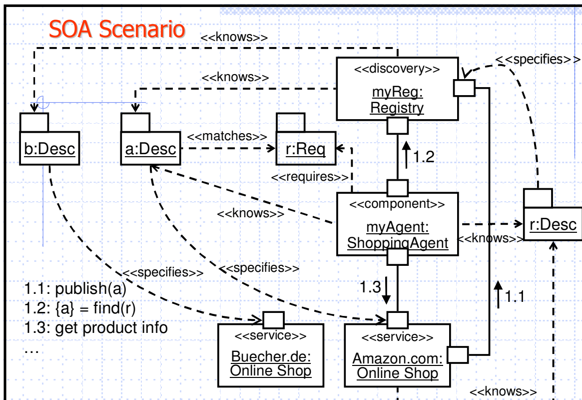
- how does myAgent know Amazon.com?
- why does myAgent not ask Buecher.de?

Service-Oriented Architectures (SOA)

A Web service is a *component* deployed on a *Web accessible platform* provided by a *service provider* to be *discovered* and *invoked* over the Web by a *service requestor*



SOA Scenario

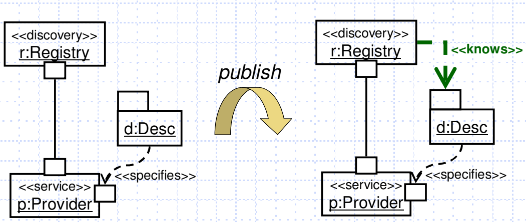


- how does myAgent know Amazon.com?
- why does myAgent not ask Buecher.de?

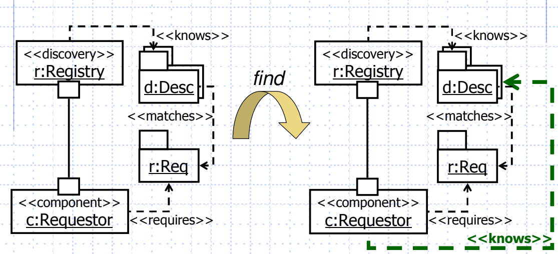
Service-Oriented Architectures (SOA)

- What are the rules of the game?
- What can we do to reach configuration where X can talk to Y?

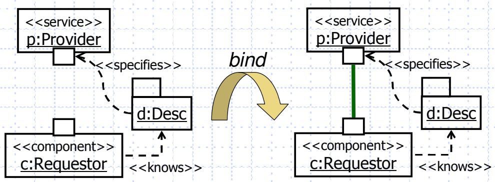
SOA Rules: Publishing a service description at a registry



SOA Rules: Discovering service descriptions satisfying requirements



SOA Rules: Binding to a service based on its descriptions



Service-Oriented Architectures (SOA)

- What are the rules of the game?
  - full spec of about 25 rules
  - based on a meta model structured into 3 packages
- What can we do to reach configuration where X can talk to Y?
  - a reachability property …

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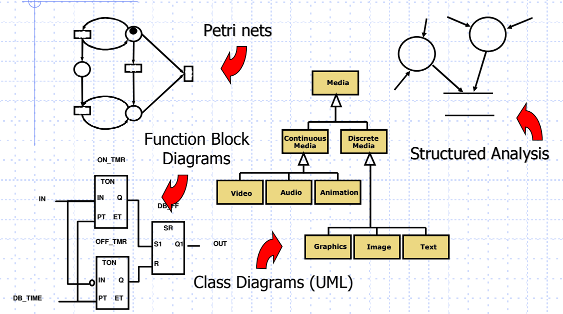
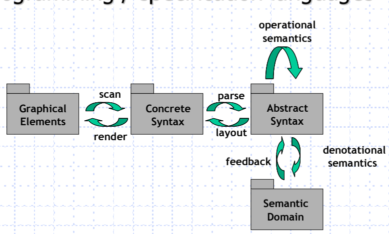
Visual Modeling Techniques



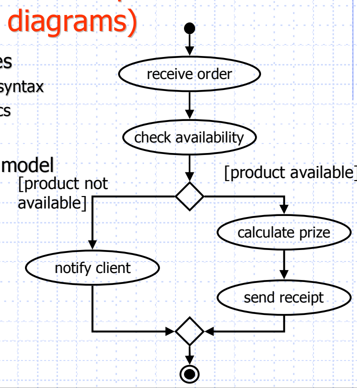
What do we need?

- Concepts, theory, tools like for textual programming / specification languages



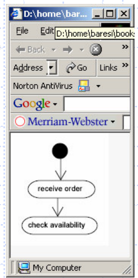
Let's try with an example (UML Activity diagrams)

- UML spec provides
  - formally defined syntax
  - informal semantics
- Semantics of the model depends on
  - semantics of the language



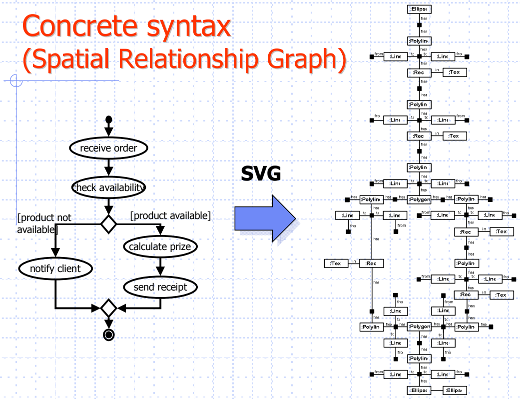
Graphical elements
(SVG – Scalable Vector Graphics)

```
<?xml version="1.0" encoding="utf-8" ?>
<ellipse cx="65" cy="24" rx="10.0" ry="10.0" style="fill:#000000;
    stroke:#000000; stroke-width:1"/>
<rect x="23" y="63" width="88" height="23" rx="16" ry="16"
    style="fill:none; stroke:#000000; stroke-width:1"/>
<text x="36" y="77" style="font-family:Dialog; font-size:10;">
    receive order</text>
<rect x="15" y="111" width="99" height="23" rx="16" ry="16"
    style="fill:none; stroke:#000000; stroke-width:1"/>
<text x="23" y="125" style="font-family:Dialog; font-size:10;">
    check availability</text>
<polyline style="fill:none; stroke:#000000; stroke-width:1"
    points="66,33 66,63"/>
<line x1="59" y1="50" x2="66" y2="62" style="fill:#000000;
    stroke:#000000; stroke-width:1"/>
<line x1="73" y1="50" x2="66" y2="62" style="fill:#000000;
    stroke:#000000; stroke-width:1"/>
<polyline style="fill:none; stroke:#000000; stroke-width:1"
    points="62,86 62,111"/>
...
</svg>
```

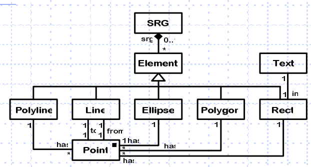


Graphical Elements

Concrete syntax
(Spatial Relationship Graph)



How can we create this?

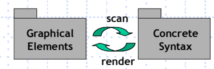


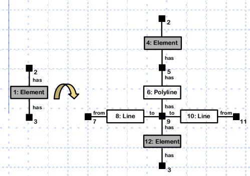
Typed graph (metamodel)

- Textual attributes
- Pairs of rules
- Shared metamodels

Concrete Syntax

An example rule





<1: element> := <2: element>
<3: polyline>
<4: line>
<5: line>
<6: element>

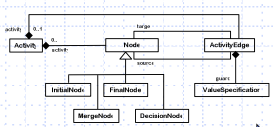
Attributes
1.x1 = 2.x1
1.y1 = 2.y1
1.x2 = 6.x2
1.y2 = 6.y2

Conditions
3.points = 2.x2, 2.y2 6.x1, 6.y1
4.x1 = 6.x1-7 4.y1 = 6.y1-12 4.x2 = 6.x1 4.y2 = 6.y1
5.x1 = 6.x1+7 5.y1 = 6.y1-12 5.x2 = 6.x1 5.y2 = 6.y1

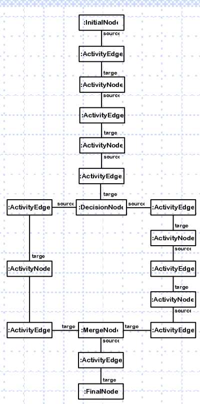
Scanning

Rendering

Abstract syntax



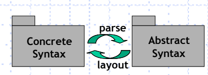
Metamodel

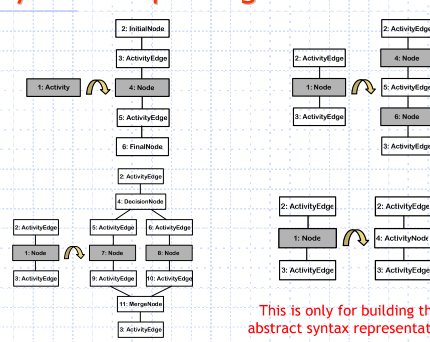


Abstract Syntax graph

Abstract Syntax

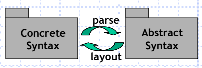
Layout and parsing



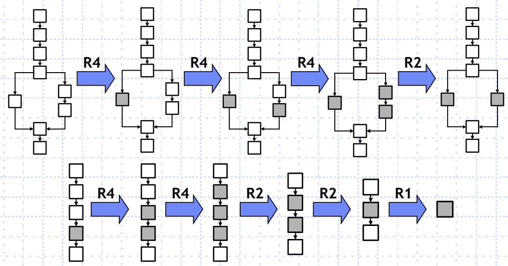


This is only for building the abstract syntax representation

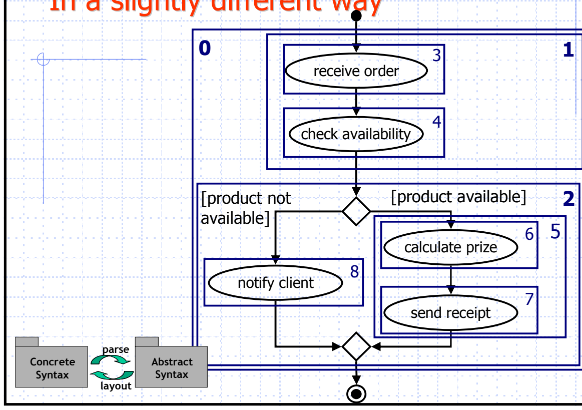
Example parsing steps



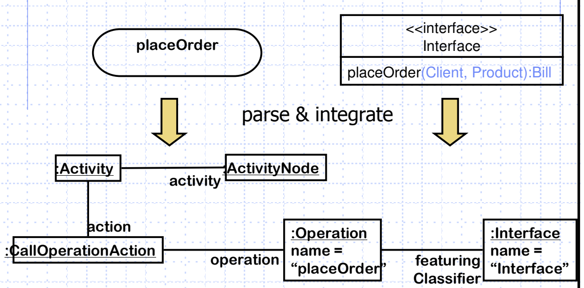
- Rules are applied right to left



In a slightly different way

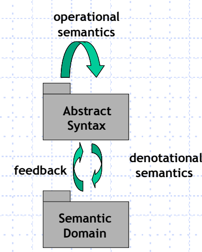


Integrated representations



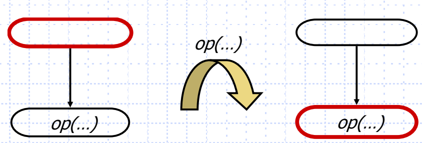
Semantics

- Operational: abstract interpreter
  - concrete syntax: animation rules
  - abstract syntax: graph transformation rules
- Denotational: mapping to semantic domain
  - analyze model (cf. compiler front-end)
  - generate semantic representation (cf. compiler back-end)

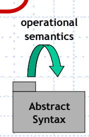


Operational Semantics

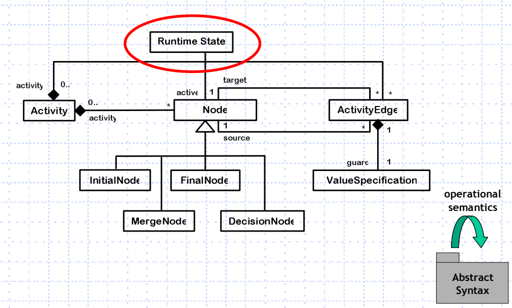
- diagram syntax plus *runtime state*
- visual rules to model state transitions

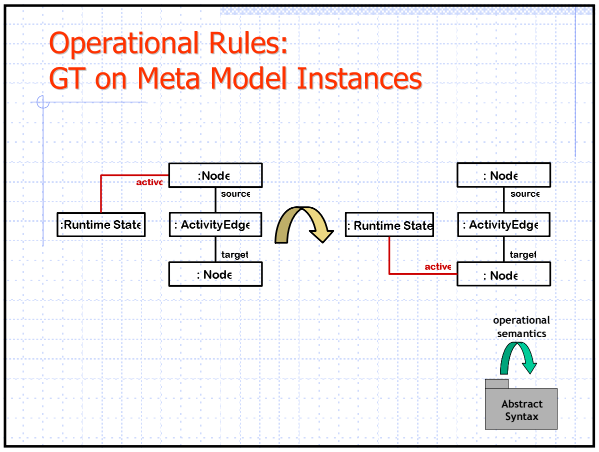


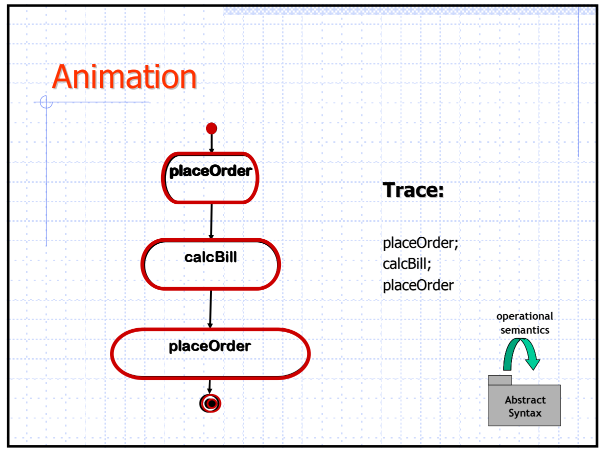
- produce sequences of states / labels, visualized as animations

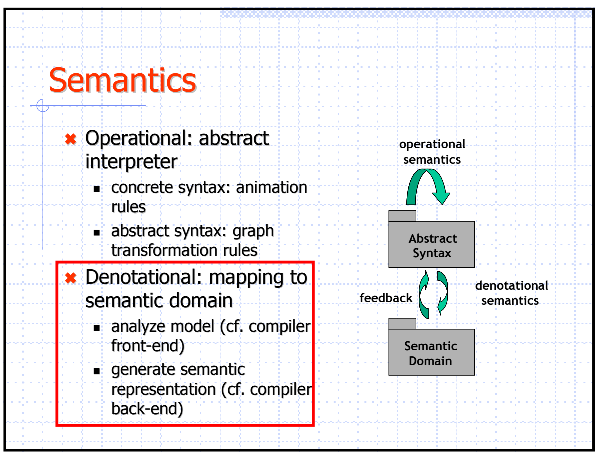


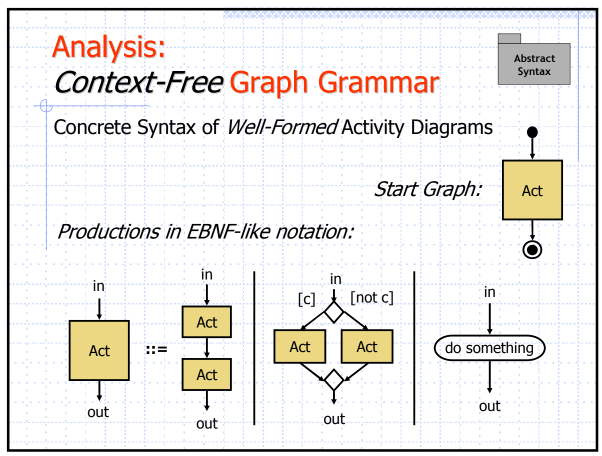
Extended Meta Model: Original Fragment plus *Runtime State*

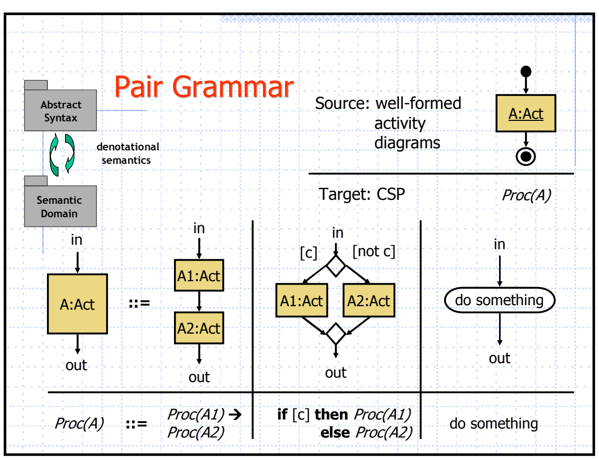


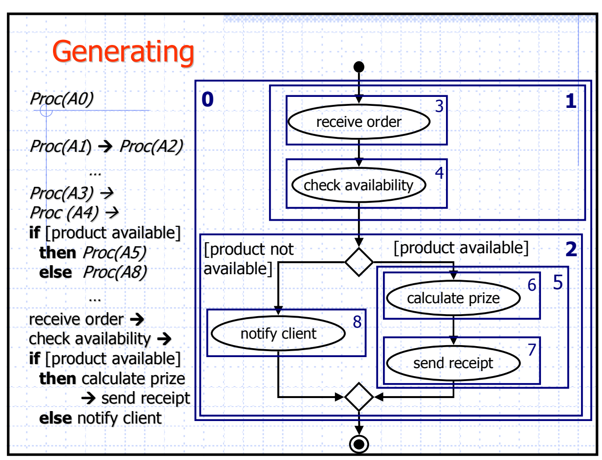

Operational Rules:
GT on Meta Model Instances
:Node
active
source
:Runtime State
: ActivityEdge
target
: Node
: Node
source
: Runtime State
: ActivityEdge
target
active
: Node
operational semantics
Abstract Syntax


Animation
placeOrder
calcBill
placeOrder
Trace:
placeOrder;
calcBill;
placeOrder
operational semantics
Abstract Syntax


Semantics
Operational: abstract interpreter
concrete syntax: animation rules
abstract syntax: graph transformation rules
Denotational: mapping to semantic domain
analyze model (cf. compiler front-end)
generate semantic representation (cf. compiler back-end)
operational semantics
Abstract Syntax
feedback
denotational semantics
Semantic Domain


Analysis:
Context-Free Graph Grammar
Abstract Syntax
Concrete Syntax of Well-Formed Activity Diagrams
Start Graph:
Act
Productions in EBNF-like notation:
in
Act
out
::=
in
Act
Act
out
in
[c]
[not c]
Act
Act
out
in
do something
out


Abstract Syntax
denotational semantics
Semantic Domain
Pair Grammar
Source: well-formed activity diagrams
A:Act
Target: CSP
Proc(A)
in
A:Act
out
::=
in
A1:Act
A2:Act
out
in
[c]
[not c]
A1:Act
A2:Act
out
in
do something
out
Proc(A)
::=
Proc(A1) → Proc(A2)
if [c] then Proc(A1) else Proc(A2)
do something


Generating
Proc(A0)
Proc(A1) → Proc(A2)
...
Proc(A3) →
Proc (A4) →
if [product available]
then Proc(A5)
else Proc(A8)
...
receive order →
check availability →
if [product available]
then calculate prize
→ send receipt
else notify client
0
1
3
receive order
4
check availability
[product not available]
[product available]
2
6
5
calculate prize
8
notify client
7
send receipt

Feedback

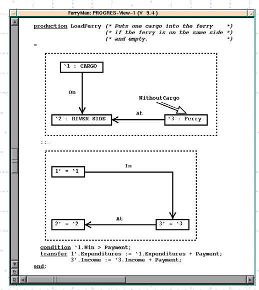
- We need to keep track of the mapping created to establish some reverse transformation.
- This means triple graph grammars (see slides at the School, www.segravis.org/school).

Tool support

Outline

- Two main groups:
  - General purpose modeling environments
    - PROGRES, AGG, Fujaba, …
  - Environments for specifying visual notations
    - DIAGEN, GENGEd, MetaEnv, ConWork, …
- Good prototype tools developed in academia

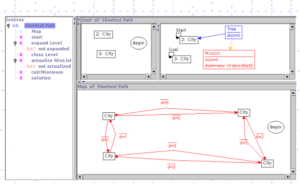
PROGRES
(PROgrammed Graph Rewriting Systems)



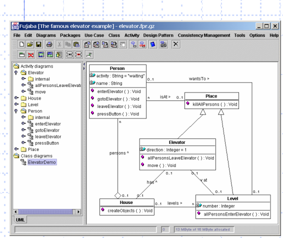
- Graphical/textual language to specify graph transformations
- Graph rewrite rules with complex and negative conditions
- Cross compilation in Modula 2, C and Java

AGG
(The Attributed Graph Grammar System)

- Algebraic approach to graph transformation
- Annotations are in Java
- Efficient graph parsing
  - Parse grammar
  - Critical pair analysis
- Easy integration with Java code

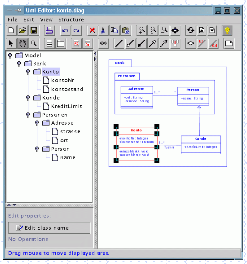


Fujaba
(From UML to Java and BAck)



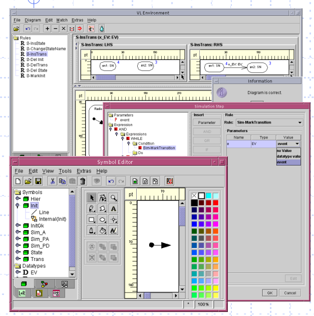
- Round trip engineering with UML, Java, and design patterns
- Class, collaboration and activity diagrams for story diagrams
  - Dynamic behavior
  - Automatic generation
- Reverse engineering

DiaGen
(The Diagram Editor Generator)



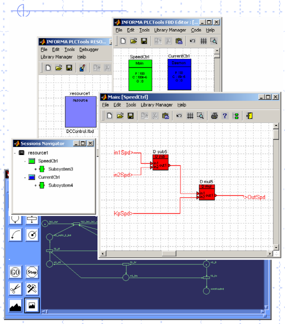
- Notations are specified through hypergraphs
- Framework of Java classes
  - to provide basic functionality
- Generator program
  - to produce Java source code

GenGED
(Generation of Graphical Env.s for Design)



- Graphical editors and simulation environments
  - Syntax grammar
    - Actual syntax
  - Parse grammar
    - Free-hand editing
  - Simulation grammar
    - To simulate models
- AGG and graphical constraint solving techniques

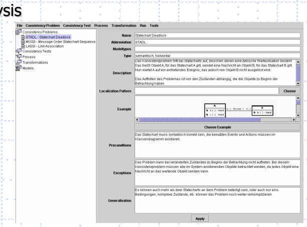
MetaEnv



- Customizable engine to map diagram notations onto high-level timed Petri nets
- Rules are pairs of graph grammars
- Results are mapped back onto the diagram model

ConWork
(Consistency Workbench)

- GT to translate models into CSP
- rule-based generation of constraints
- visual definition of analysis process
- catalog of consistency problems



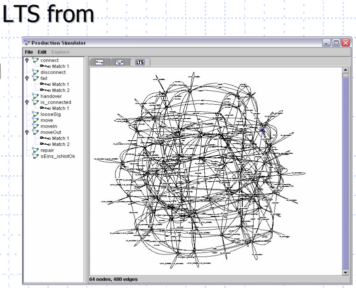
- Contact:
  - Jochen Kuester
    U. of Paderborn
    jkuester@upb.de

Analysis

- CheckVML
  - Encodes graph transformation systems into SPIN to reason on the reachability of specific configurations by means of sequences of rules
- Groove
  - Verifies model transformation and dynamic semantics through an (automatic) analysis of the resulting graph transformation systems using model checking

GRaphs for Object-Oriented VErification (GROOVE)

- generation of LTS from GT systems
  - edge-labelled graphs
  - application conditions
  - priorities



http://wwwhome.cs.utwente.nl/~groove/groove-index

Conclusions

Main results

- The tutorial has
  - Motivated the use of graph transformation in software engineering
  - Introduced the foundations of graph transformation
  - Shown example applications of graph transformation
    - GT as semantic domain for behavior modeling
    - GT as meta language for visual modeling techniques
  - Presented available tools
- Now, attendees are likely to be able to
  - Better understand the different proposals
  - Better evaluate if and how they can exploit it in their work

Future work
(Applications)

- GT should become more "usable" by non experts:
  - It should be better disseminated (This tutorial)
  - More examples and case studies to "convince" skeptical users
  - Further co-operations between GT experts and domain experts
  - More friendly tools (even if they are much better than a few years ago)

Future work
(Foundations)

- analysis and verification techniques
- refinement and modularity
- relation with other areas
  - process calculi (Milner, Montanari)
  - DNA computing (Rozenberg)
  - XML, Meta data, Semantic Web (Rising)

Research Training Network *SegraVis** [10/02 – 9/06]

You want to learn more?

- Apply for a grant with one of 12 European partners in Belgium, Germany, Italy, NL, and UK (only citizens of EU and associated)
- Participate in our network events

For details, see www.segravis.org or contact Reiko Heckel

* *Syntactic and Semantic Integration of Visual Modeling Techniques*

A few basic references

- Handbook of Graph Grammars and Computing by Graph Transformation
  1. Foundations
  2. Applications, Languages and Tools
  3. Concurrency, Parallelism, and Distribution
- Graph Transformation for Specification and Programming
  Andries, Engels, Habel, Hoffmann, Kreowski, Kuske, Plump, Schürr, Taentzer; Science of Computer Programming, Vol. 34, No. 1, April 1999, pp.1-54
- Tutorial Introduction to Graph Transformation: A Software Engineering Perspective
  Baresi, Heckel; Proc. 1st Intl. Conference on Graph Transformation (ICGT 02), Barcelona, Spain, Springer LNCS 2505

Web sites

- Home of the ICGT steering committee
  - www.gratra.org
- SegraVis home page
  - www.segravis.org
- Graph Grammar Bibliography
  - www.informatik.uni-bremen.de/theorie//appligraph/bibliography.html
- AGG home page
  - tfs.cs.tu-berlin.de/agg/
- PROGRES home page
  - www-i3.informatik.rwth-aachen.de/research/projects/progres/
- DiaGen home page
  - www2.informatik.uni-erlangen.de/DiaGen/
- GenGED home page
  - tfs.cs.tu-berlin.de/~genged/

Open discussion

Our Addresses

- Luciano Baresi
  - Politecnico di Milano
    Dipartimento di Elettronica e Informazione
    Piazza L. da Vinci, 32 – I20133 Milano (Italy)
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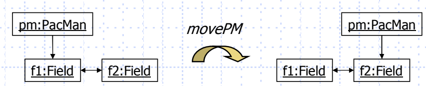
- Reiko Heckel
  - University of Paderborn
    Faculty of Computer Science Electrical Engineering and Mathematics
    D-33095 Paderborn (Germany)
    reiko@upb.de

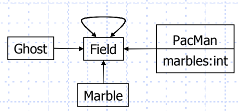
Exercise 1: Be a (slightly) more clever player!

Extend the *movePM* rule so that *Pacman* does not move next to a *Ghost*.



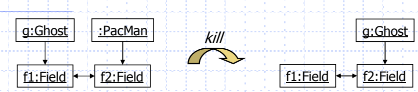
Exercise 2: Give *Pacman* another chance

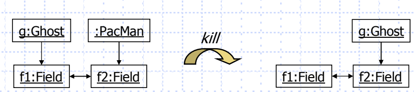
Let *Pacman* have a counter for his lives.



Refine the rule *kill* to remove *Pacman* only if he has run out of lives. Otherwise decrease the counter and remove the *Ghost*.

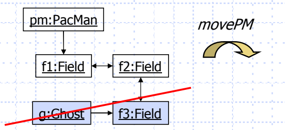
Refine rule *kill*





Solution 1: Be a (slightly) more clever player!

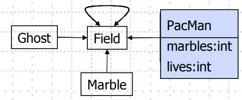
Extend the *movePM* rule so that *Pacman* does not move next to a *Ghost.*



Solution: a negative application condition.

Solution 2: Give *Pacman* another chance

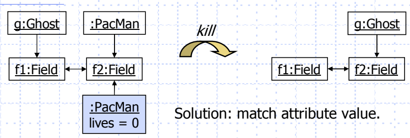
Let *Pacman* have a counter for his lives.



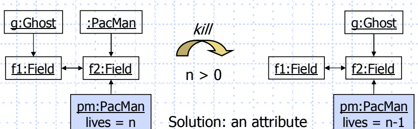
Solution: add an attribute.

Refine the rule *kill* to remove *Pacman* only if he has run out of lives. Otherwise decrease the counter and remove the *Ghost*.

Refine rule *kill*



Solution: match attribute value.



Solution: an attribute application condition.