# Introduction to Software Evolution

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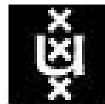


Universiteit van Amsterdam

# Global Schedule

Lectures

Wednesday: 09:00 – 11:00 week 44 – 51 (inclusive)
in SP A1.04

Lab (deadlines in the pdf on Blackboard Assignments)

Wednesday: 11:00 – 17:00 in SP G0.10 & G0.12
Thursday: 09:00 – 17:00 in SP D1.111

Paper sessions (essay deadlines in the same pdf)

Every other week (Friday morning, various locations)

# Courses

- Intro (*Paul Klint*)
- Rascal (*Jurgen Vinju*)
- Software Assessment (*Joost Visser*, SIG)
- Mining Software Repositories (*Jurgen Vinju*)
- Visualization (*Paul Klint*)
- Refactoring (*Jurgen Vinju*)

# Grades

- Series 0 has no grade, but it trains you for the...
- … required Online lab test (Rascal) > 50% correct
- 1/3 Paper Sessions, required > 5.5
- 1/3 Series 1, required > 5.5
- 1/3 Series 2, required > 5.5
- Overall average required > 5.5

# Today!

- 9-11 Introduction to Software Evolution
- 11-13:40 Getting started with Series 0
  - this includes lunchtime
  - in G0.10 & G0.12
- 13:40-14:00 walk to CWI and find room
  - L017 on the ground floor
- 14:00-16:00 Overview slides Rascal

# Lab project (Series 1)

- Software Assessment
  - **Measuring** source code
  - To find **indications** of good/bad quality
  - **Predicting** hard to maintain, costly, source code
- Software Metrics
  - Mechanics using Rascal
  - Definition and correctness
  - Aggregation
  - Interpretation

# Lab project (Series 2)

- Reverse Engineering
  - From source code to design
  - Visualization
- Software Visualization
  - Mechanics using Rascal
  - Software Exploration
  - Software Understanding
  - Link with metrics

# Lab project (Advanced Track)

- On demand
- Personalized
- Instead of series 2
- Typical project: reproduce the experimental results of a recent research paper in the software evolution domain.
- Very challenging!
- Grading: a successful project gives extra points!

# Paper sessions

- There is no book with this course
- Instead we read papers about software evolution and discuss them
- You write an outline of a paper: stepping stone towards a great masters thesis!
- Feedback from teachers and lab assistants
- Blackboard -> Assignments

# Tentative list of paper topics

- What are software metrics for? What is problematic with their interpretation and how can this be solved?
- What is the problem with aggregation of software metrics? How can this problem be solved?
- How can “mining software repositories” help in software research or software maintenance?
- What is the role of program transformation in software evolution (refactoring)?

# Hints about paper

- Choose something a lot more specific
- We create a paper outline in 3 steps:
  - Topic + motivation
  - Argumentation & literature
  - Title & Abstract
- Use what you've learned from previous paper sessions (finding and reading literature)
- Read what you are judged on (see lab pdf)

# Roadmap

- The Software Volcano
- Introduction to Software Maintenance & Evolution
- Introduction to Software Renovation
- Introduction to Program Analysis and Transformation
- Wrapping up

# Software Volcano

Mt. Etna, Sicily, Italy

# The Software Volcano: Languages

Distribution of languages in use, worldwide

| Language | Used in % of total |
|---|---|
| COBOL | 30 |
| Assembler | 10 |
| C | 10 |
| C++ | 10 |
| 550 other languages | 40 |

- For mainframe applications 80% is COBOL!
- Figures taken from Capers Jones (Software Productivity Research)

# Software Volcano: Volume

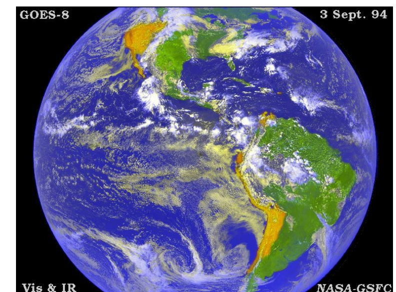
- The total volume of software is estimated at $7 * 10^9$ *function points*
- 1 FP = 128 lines of C or 107 lines of COBOL
- The volume of the volcano is
  - 750 Giga-lines of COBOL code, or
  - 900 Giga-lines of C code

Printed on paper we can wrap planet Earth 9 times!

# Software Volcano: Defects

- Observation:
  - on average 5 errors (bugs) per function point
  - includes errors in requirements, design, coding, documentation and bad fixes
- The software volcano, world-wide, contains
  $5 * 7 * 10^9$ Bugs = 35 Giga Bugs

This means 6 bugs per human being on planet Earth!



# Work distribution of programmers

| Year | New projects | Enhancements | Repairs | Total |
|---|---|---|---|---|
| 1950 | 90 | 3 | 7 | 100 |
| 1960 | 8,500 | 500 | 1,000 | 10,000 |
| 1970 | 65,000 | 15,000 | 20,000 | 100,000 |
| 1980 | 1,200,000 | 600,000 | 200,000 | 2,000,000 |
| 1990 | 3,000,000 | 3,000,000 | 1,000,000 | 7,000,000 |
| 2000 | 4,000,000 | 4,500,000 | 1,500,000 | 10,000,000 |
| 2010 | 5,000,000 | 7,000,000 | 2,000,000 | 14,000,000 |
| 2020 | 7,000,000 | 11,000,000 | 3,000,000 | 21,000,000 |

Now: 60% of the programmers work on enhancement and repair

In 2020: only 30% of all programmers will work on new software

# Message

- When an industry approaches 50 years of age it takes more workers to perform maintenance than to build new products (*ex:* automobile industry)
- Maintenance and renovation of existing software become more and more important: avoid that the software volcano explodes

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- Introduction to Software Renovation
- Introduction to Program Analysis and Transformation
- Course Overview *Software Evolution*

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# Introduction to Software Maintenance & Evolution

- What is Software Maintenance?
- Why does software evolve?
- Problems in Software Maintenance
- Solutions

# What is Software Maintenance?

- Modification of a software product after delivery to correct faults, to improve performance or other attributes, or to adapt the product to a modified environment (IEEE 1219, 1993)
- Observe that:
  - maintenance is seen as after-the-fact activity
  - no integration with software development process

# Another Classification

- Software maintenance
  - Changes are made in response to changed requirements
  - The fundamental software structure is stable
- Architectural transformation
  - The architecture of the system is modified
  - Generally from a centralised to a distributed architecture
- Software re-engineering
  - No new functionality is added to the system but it is restructured and reorganised to facilitate future changes

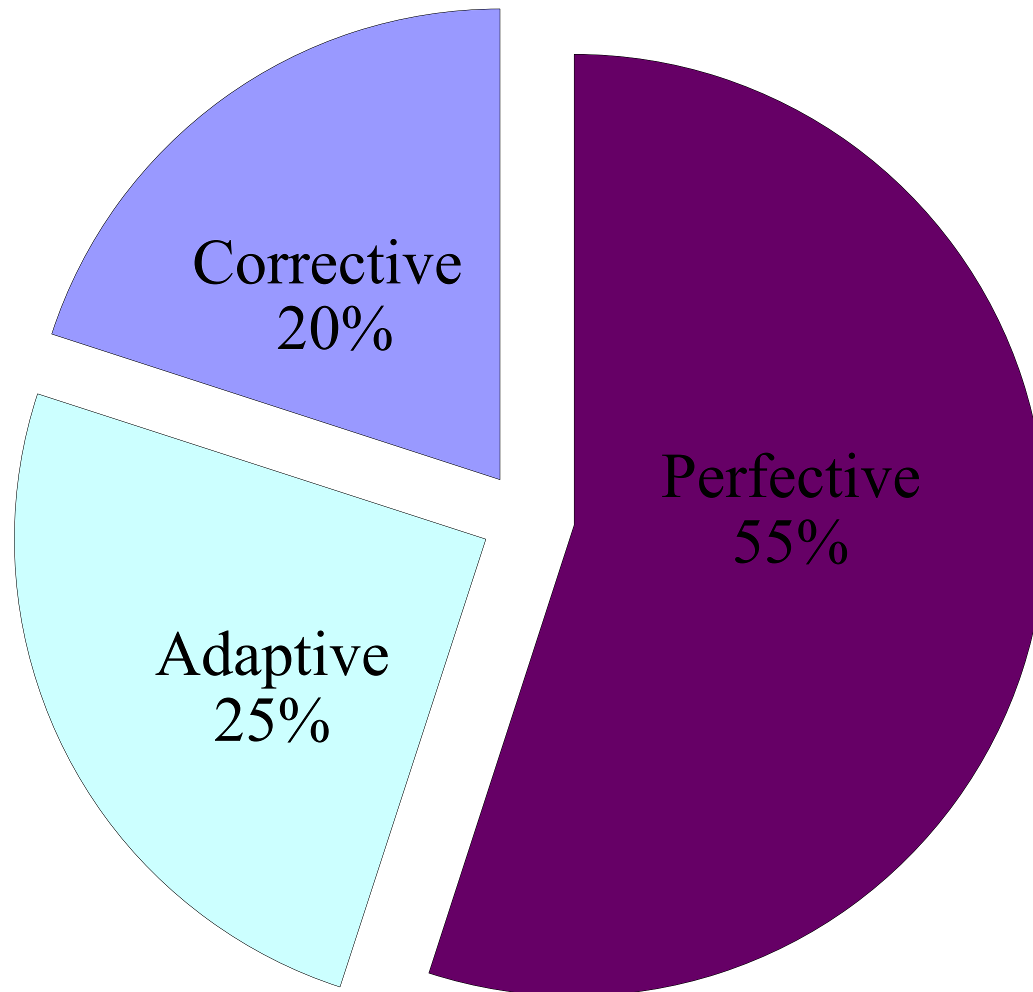
# Why systems change

- Correct errors
- Business pull:
  - Business / IT alignment
  - Requirements change (legislation, new insights, efficiency)
  - Re-organization
  - Mergers / take-overs
  - New products, marketing actions
  - Market hypes (CRM, ERP, BPR, STP)
- Technology push:
  - Internet
  - Mobile
  - Updates of operating system, development environment, databases
  - Hardware

# Categories of Maintenance

- Corrective: needed to correct actual errors
- Adaptive: result from changes in the environment
- Perfective: modifications to meet the expanding needs of the user
- Enhancement = Adaptive + Perfective

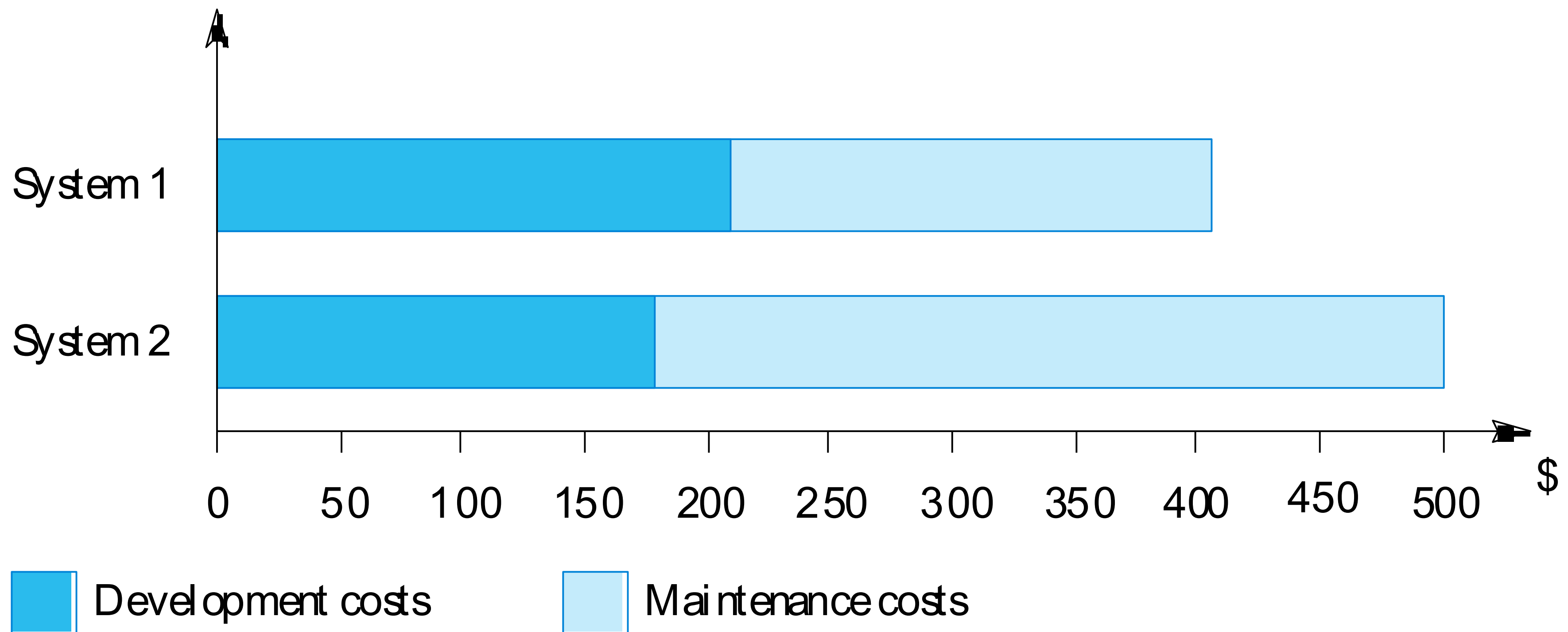
# Cost Distribution per Category



# Costs of Maintenance

- Usually greater than development costs
  - 2* to 100* depending on the application
- Affected by both technical and non-technical factors
- Increases as software is maintained
  - Maintenance corrupts the software structure, making further maintenance more difficult
- Ageing software can have high support costs
  - old languages, compilers etc.
- Think of your software as continuously evolving

# Cost distribution of two systems



# Cost factors

- Team stability
- Contractual responsibility
- Staff skills
- Program age and structure

# Costs and Complexity

- Predictions of maintainability costs can be made by assessing the complexity of system components.
- Most maintenance effort is spent on a relatively small number of system components.
- Complexity depends on
  - Complexity of control structures;
  - Complexity of data structures;
  - Object, method (procedure) and module size
  - Dependencies
  - ***Understandability & Changeability***

# Lehman’s Laws for Software Evolution

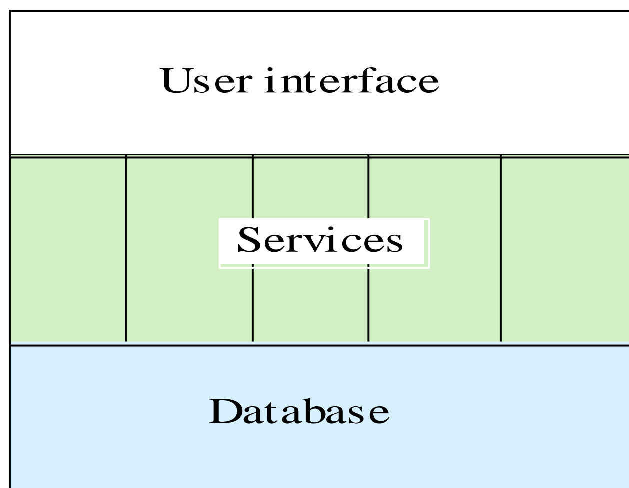
- Lehman observed that software evolves
- Law of Continuing Change: software needs to change in order to stay useful
- Law of Increasing Complexity: the structure of a program deteriorates as it evolves
  - the structure of a program degrades until it becomes more cost effective to rewrite it

# An Example (*Civility*)

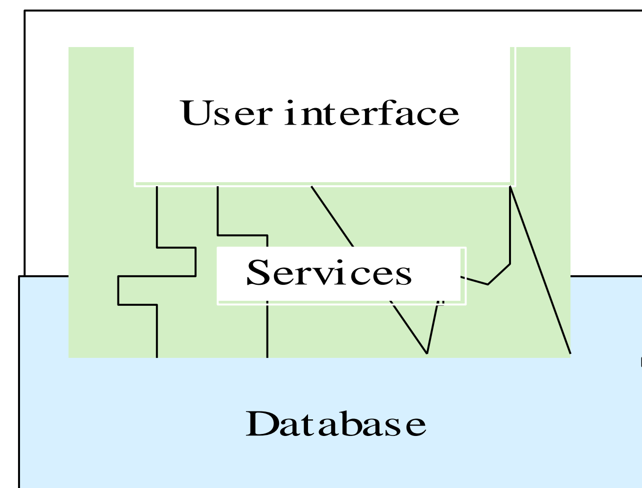
- Software for city administration; Old, successful, reliable
  - ➔ large client base
- Complex code (performance, size, many changes)
- No clear separation between Data, Business, Logic and User Interface
  - ➔ High costs for maintenance, hard to change
- Need to change (internet, legislation, process management, CRM)
  - ➔ Re-engineering and migration

# Legacy systems

- Ideally, for distribution, there should be a clear separation between the user interface, the system services and the system data management
- In practice, these are usually intermingled in older legacy systems




Ideal model for distribution




Real legacy systems

# Spaghetti code

```
Start:   Get (Time-on, Time-off, Time, Setting, Temp, Switch)
    if Switch = off goto off
    if Switch = on goto on
    goto Cntrld
off:  if Heating-status = on goto Sw-off
    goto loop
on:   if Heating-status = off goto Sw-on
    goto loop
Cntrld:  if Time = Time-on goto on
    if Time = Time-off goto off
    if Time < Time-on goto Start
    if Time > Time-off goto Start
    if Temp > Setting then goto off
    if Temp < Setting then goto on
Sw-off:  Heating-status := off
    goto Switch
Sw-on: Heating-status := on
Switch:  Switch-heating
loop: goto Start
```

# Some observations from *Civility*

- Current architecture used to the max
- New requirements require new architecture
- The more stable the functionality, the more the knowledge diminishes
- These systems are *really good*!
- But nobody *knows why* anymore...
- So the *maintenance process* must be very strict:
  - maintenance costs high and flexibility low
- Limited use of tooling

# Why Systems Survive

- Organisations have huge investments in their software systems
- Systems are critical business assets
- Organizations depend on the system
- Organizations know how to use their systems
- (Re) building systems is high risk

# Business *versus* IT in Software Maintenance

- Low costs
- Opportunistic / flexible
- Quick decision making
- Reliability in short time
- IT should understand business
- Protect initial investment
- Standardization
- Problems with IT systems make companies careful
- ***Quantity***

- Need for adequate resources
- Requires planning / choices
- Hard to predict costs, impact
- Time to deliver quality
- Business should understand IT
- Want something new
- Creativity
- Unpredictability
- Why all these procedures?
- ***Quality***

# Major problems in Software Maintenance

- Inadequate testing methods
- Performance measurement difficulties
- Knowledge management / documentation
- Adapting to the rapidly changing business environment
- Large backlog

# Major problems in Software Management

- Lack of skilled staff
- Lack of managerial understanding and support
- Lack of maintenance methodology, standards, procedures & tools
- Program code is complex and unstructured
- Integration of overlapping/incompatible systems

# Solutions

- Architecture
- Refactoring
- Automated regression testing
- Knowledge management
- Automated code inspection
- Better organization -> ITIL / CMM

# Towards a Software Maintenance Process

- Maintenance should be organized as a structured process
- ISO/IEC 12207: a standard maintenance process
- ITIL: Information Technology Infrastructure Library
- CMMI: Capability Maturity Model
- Gives an impression of the scope and details of the maintenance process

# ITIL Pointers

- Pink Elephant : www.pinkelephant.com
- ITIL (Libraries) & Service Management directories: www.itil-itsm-world.com/
- British government ITIL: www.ogc.gov.uk/index.asp?id=2261
- techrepublic.com.com/5100-6329-1058517.html - Tech Republic article (subscription required)
- KU's Program & Service Management Office: www.ku.edu/~psmo

# Intermezzo; The Metaphor Game

- “Software Maintenance” and “Software Evolution” are metaphors.
- Why these words?
  - Does software wear and tear?
  - Does software procreate and does software select partners?
- What is the intented meaning?

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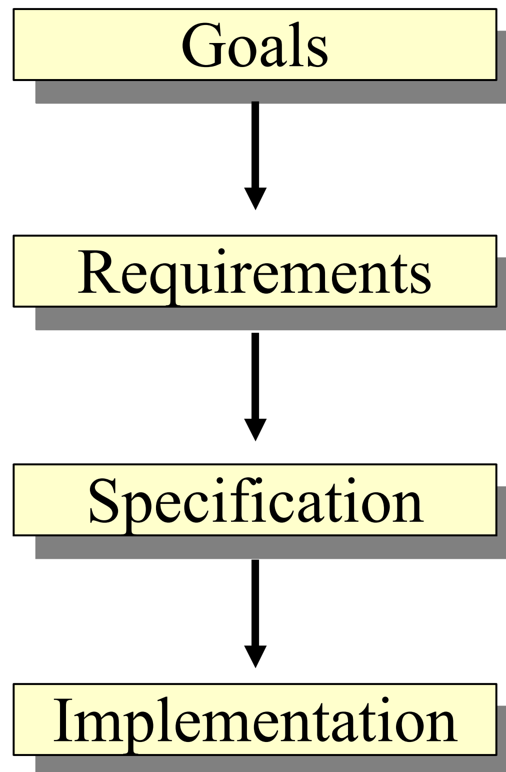
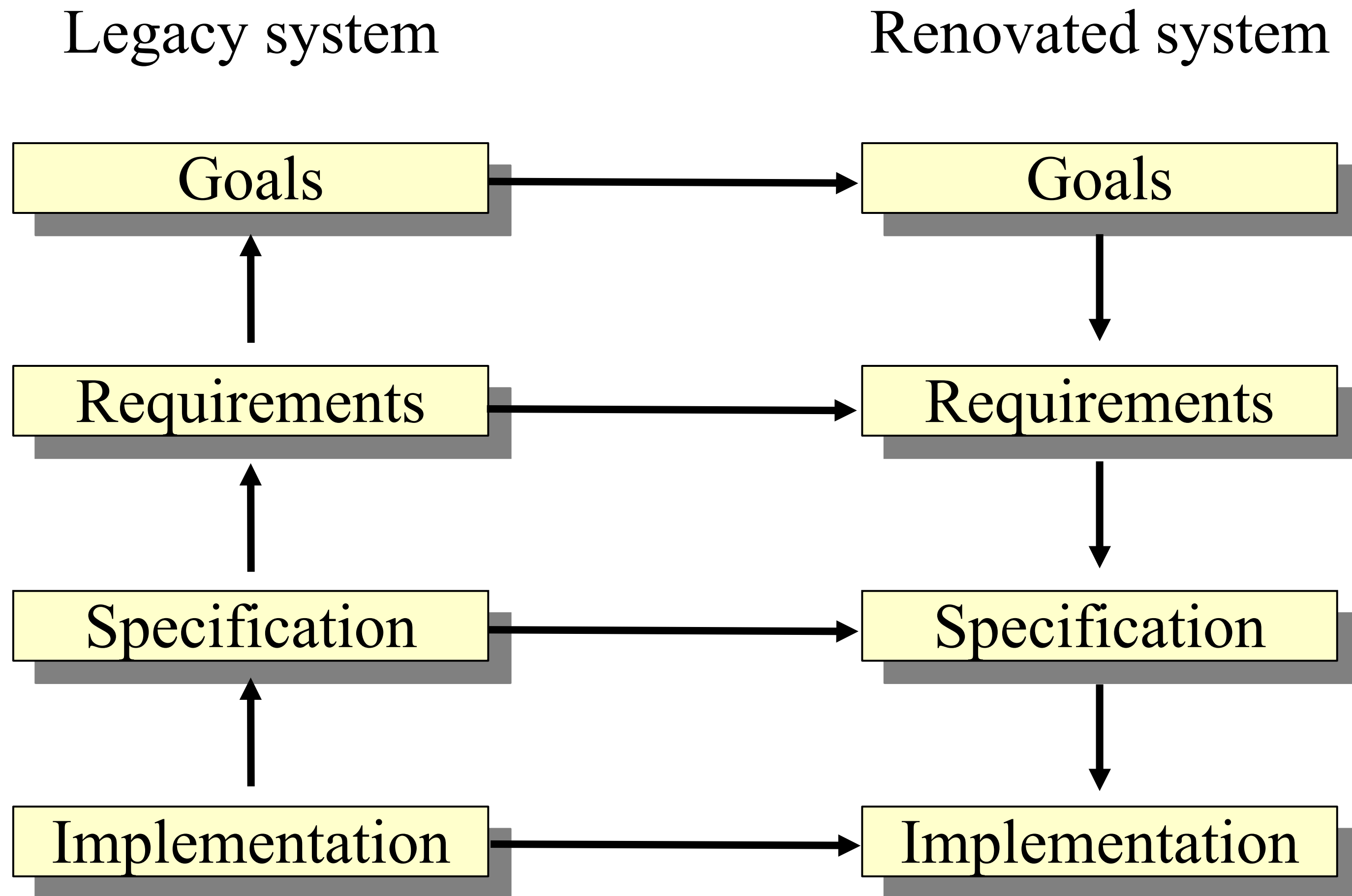
# Introduction to Software Renovation

- Legacy system:
  - (information) system that defeats further maintenance, adjustment or renewal due to its size and age
  - requires increasing maintenance costs
- System renovation:
  - understanding and improvement of legacy systems
  - by means of reverse engineering, program understanding, design recovery, transformation, ...

# Forward Engineering



# Reverse Engineering



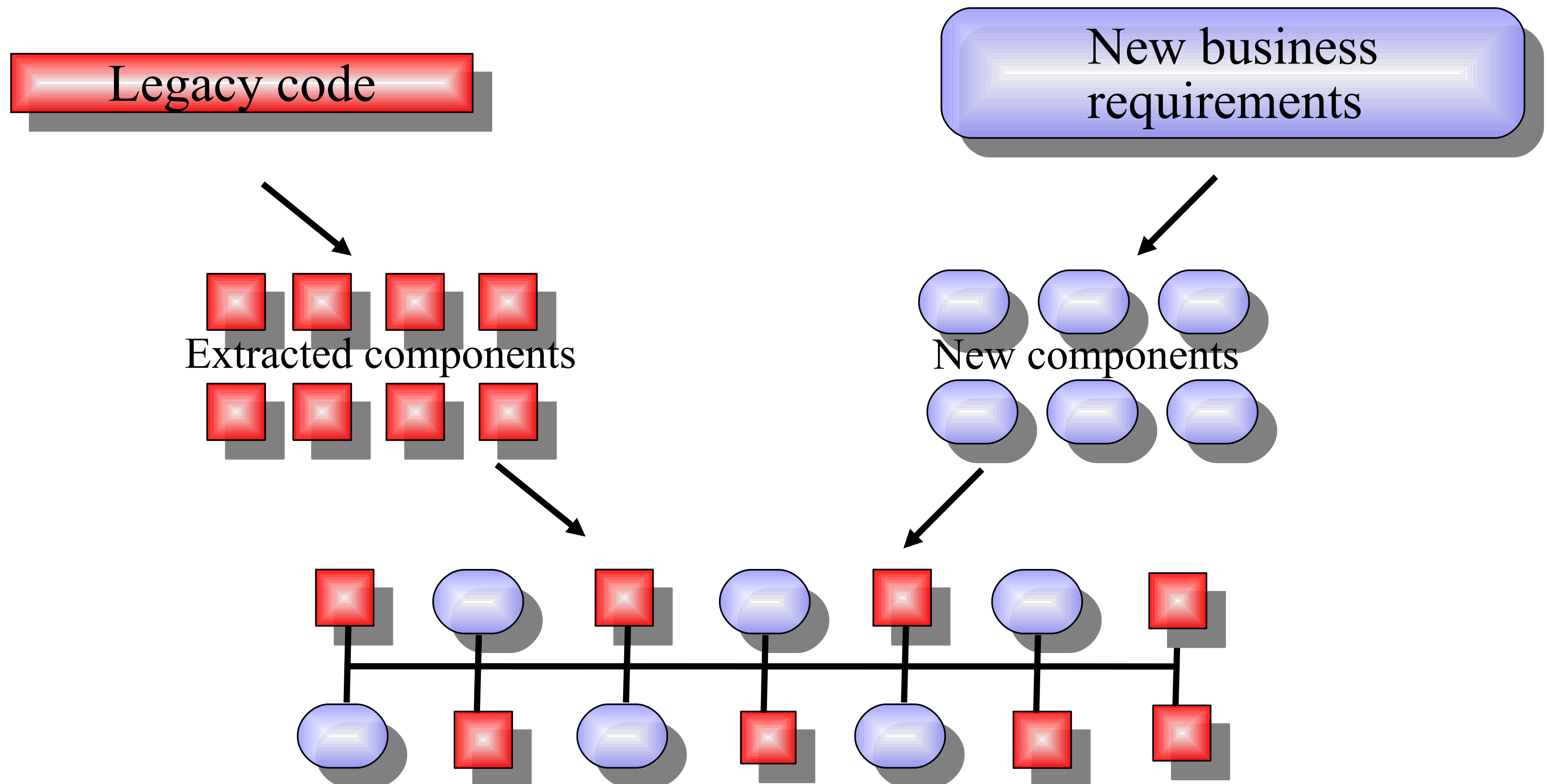
# A Typical Legacy System

- Different implementation languages
- Job Control Language scripts serve as glue
- Part of programs/databases are obsolete
- Some source text lost or incomplete; version unknown
- Documentation is incomplete or obsolete

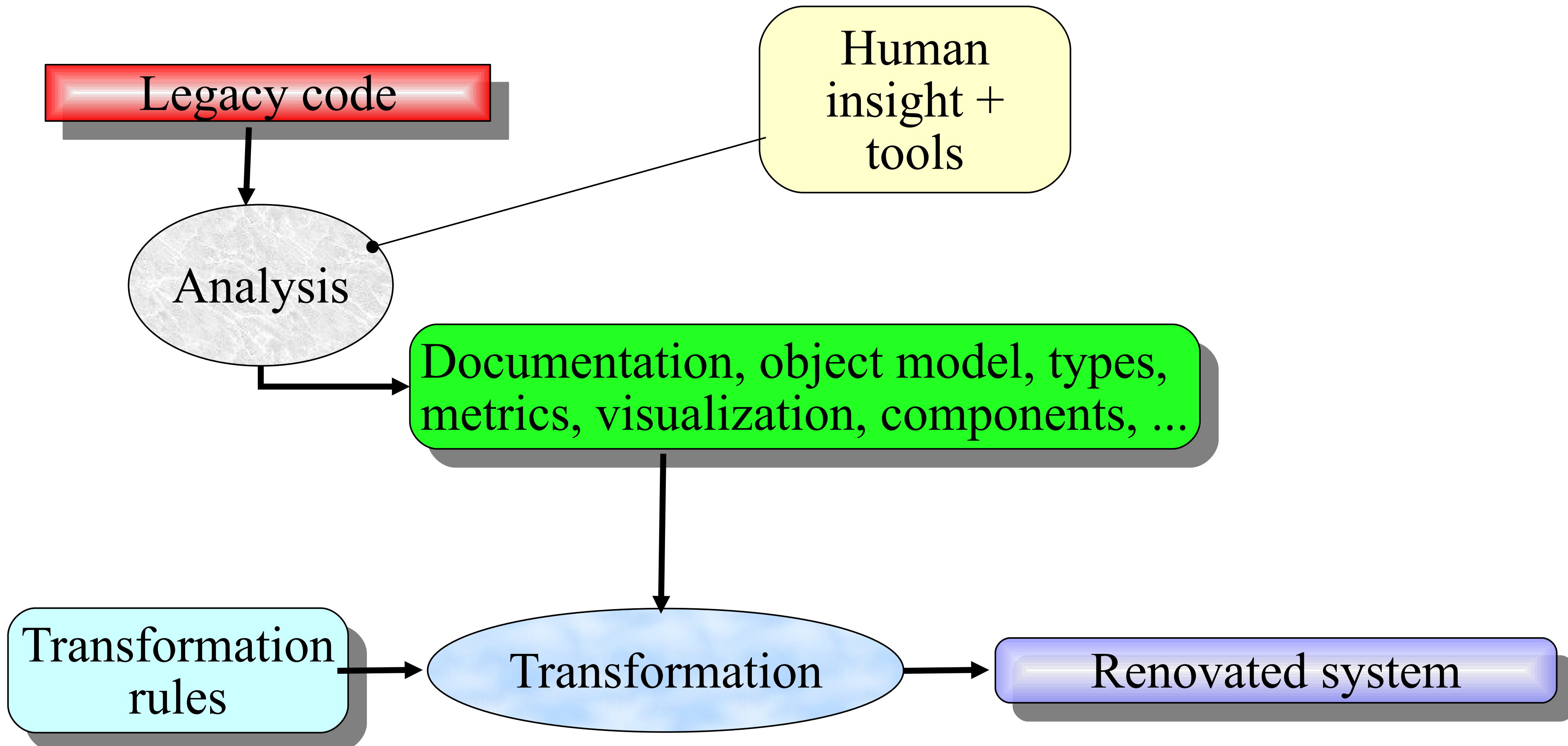
# Typical Renovation Questions

- What is the architecture of this system
- Can we improve its structure?
- Can we generate documentation for it?
- Can we migrate it from COBOL 74 to COBOL85?
- Can we connect it to Internet?
- Can we migrate it to a client/server architecture?

# Synergy between Renovated and New Components



# Renovation =
# Analysis + Transformation



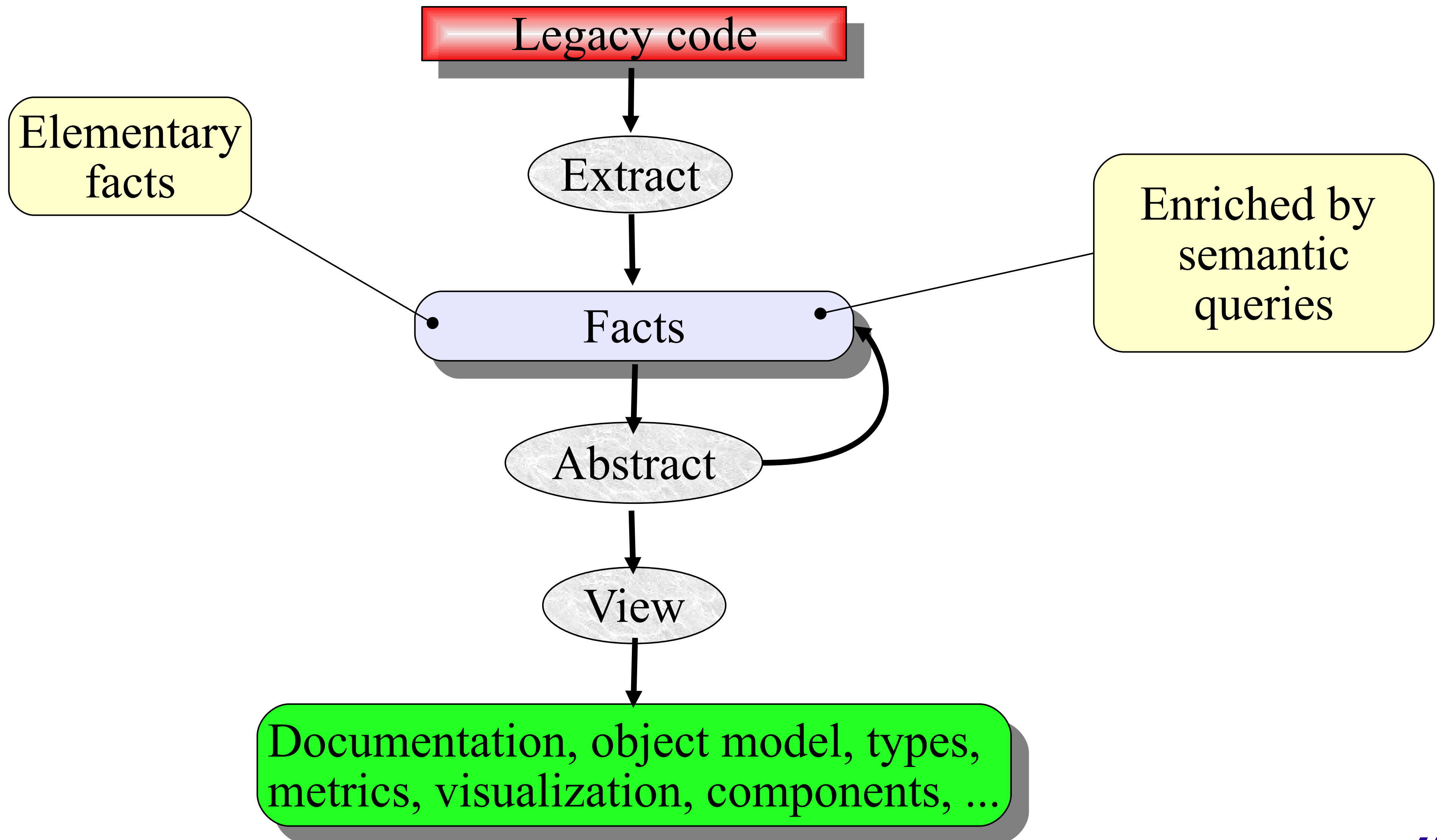
# Software Renovation

- Analysis (partly supported by tools):
  - architecture recovery
  - system understanding
- Transformation (mostly supported by tools):
  - systematic repairs
  - code improvement/dialect conversion/translation
  - architecture improvement/change

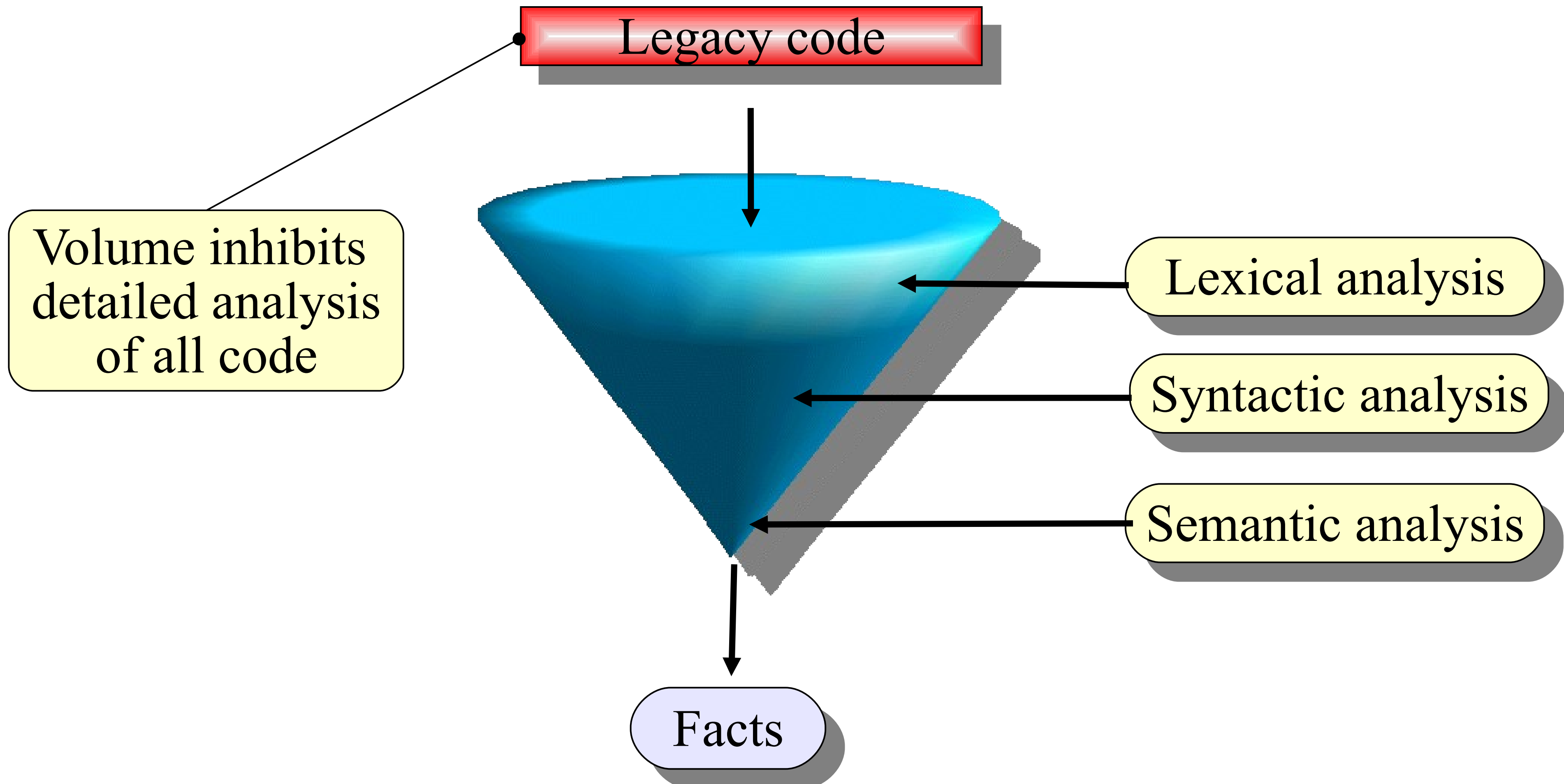
# Software Renovation: Analysis

- Extraction of procedure calls and call graph
- Database usage between programs
- Dataflow analysis (at program and system level)
- Type analysis
- Cluster and concept analysis
- Metrics
- Visualization

# Software Renovation: analysis



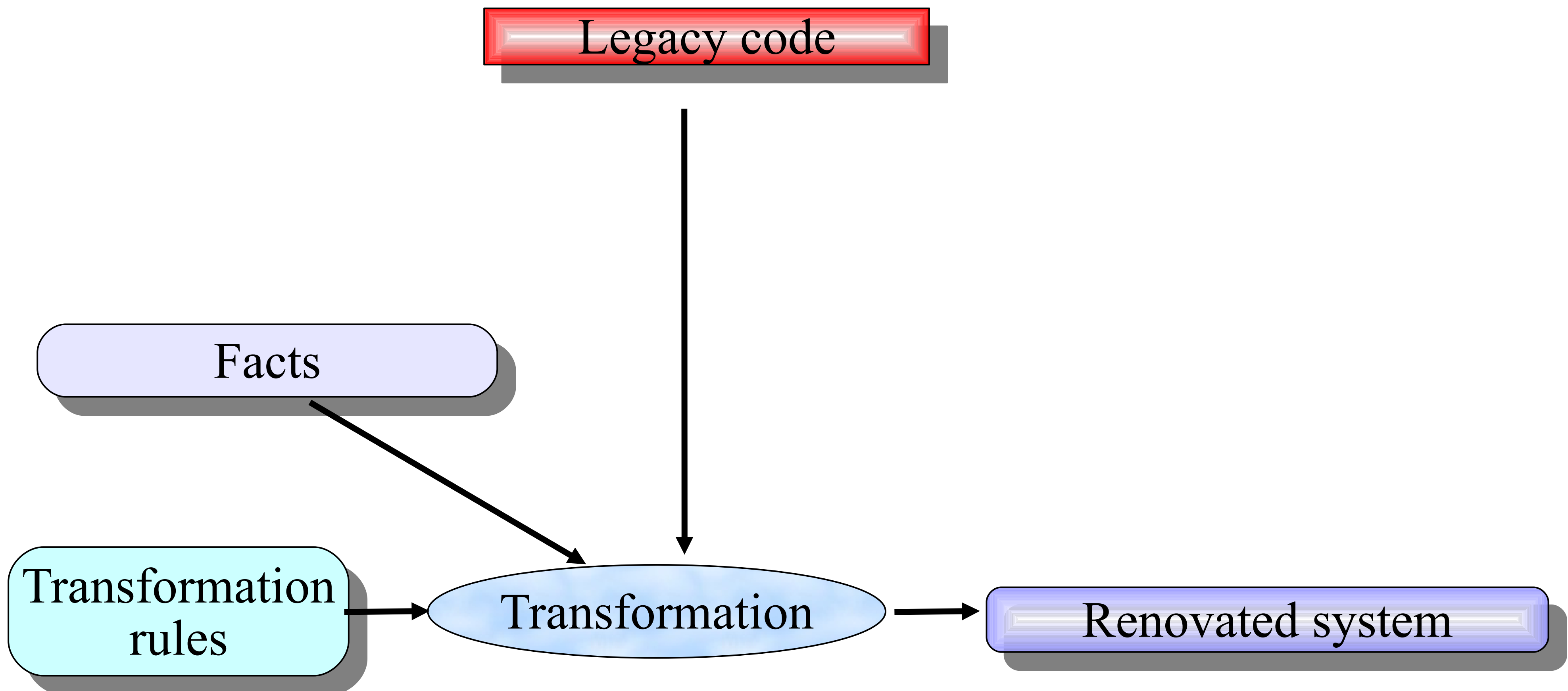
# The Analysis Funnel



# Example: DocGen

- Given the sources of a legacy system, web-based documentation is generated containing
  - overall architecture
  - module dependencies & internal structure modules
  - database usage
  - simple metrics
- Fact: code reading finds two times more defects than testing

# Software Renovation: Transformation



# Typical Transformations

- Year 2000
- Euro
- Extending bank account numbers to 10 digits
- Goto elimination
- OO restructuring
- Dialect translation  (Cobol 74 -> Cobol 85)
- Language conversion (Cobol -> Java)

# Observations

- Most legacy systems are multi-lingual
- A generic approach is needed to describe all forms of analysis and transformations for all required languages
- Languages like COBOL and PL/I are big:
  - getting the right grammar is difficult
  - many parsing techniques break down

# Needed Technologies

- Lexical scanning & Parsing
- Fact repository & queries
- Search
- Replacement

# Take home messages

- Software evolves in order to stay useful
- Maintenance (= 80% enhancement) enables this evolution
- Maintenance should be based on a well-defined process
- Software renovation is needed to extend the life cycle of a system
- Software renovation can be supported by tools

# The role of Rascal

- Rascal is designed for ***all*** this work
  - Parsing and lexical analysis
  - Relation modeling (facts!)
  - Source code locations (links!)
  - Patterns (search)
  - Visits (replacement)
- Libraries
  - Visualization
  - SVN, Git, SSH access
  - Etc. etc.

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# Introduction to Program Analysis and Transformation

- Lexical syntax
- Context-free syntax
- Static semantics
- Dynamic semantics
- Static versus dynamic analysis
- Control flow graph
- Data flow graph
- Call graph
- Examples of transformations

# Lexical Syntax

- What are the keywords (if, return, while)
- What are identifiers (rather_long_identifier)
- What are the constants (123, “a string”, false)
- What are the layout symbols (space, tab, newline)
- What are the comments (// ..., /* ... */)
- Related notions:
  - lexical grammar (describes lexical syntax)
  - lexical scanner (recognizes lexical syntax)

# Context-free Syntax

- What is the structure of declarations/statements (`if <expr> then <stat> else <stat> end`)
- Related notions:
  - grammar (describes the context-free syntax)
  - syntax analyser, parser (recognizes context-free syntax and builds a parse tree)
  - parse tree, syntax tree (tree that describes structure of a text, including all layout, keywords, etc.)
  - abstract syntax tree (parse tree with textual elements like layout, keywords, etc. removed)

# Static Semantics

- Pre-execution meaning of language elements:
  - are all variables declared?
  - are all expressions type correct?
  - are all procedure/methods called with correct parameters?
- Static semantics is conservative: run-time values are unknown and all possibilities should be considered
- Related notions:
  - type checking, compile-time analysis, model checking, abstract interpretation

# Dynamic Semantics

- Execution-time meaning of language elements:
  - what is the effect of an assignment?
  - what is the value of an expression?
  - which method should be called?
  - what is the result of executing a procedure call?
- Execution behaviour depends on specific input values
- Related notions:
  - run-time semantics, interpreters, compilers

# Static versus Dynamic Analysis, 1

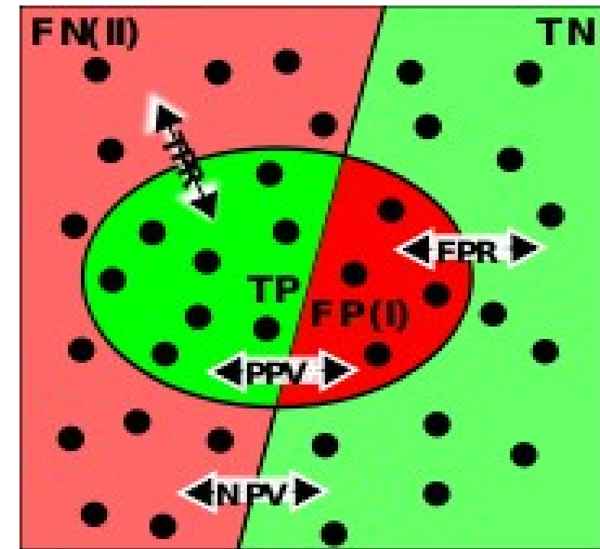
- Many analysis problems can be solved with only static analysis:
  - count number of class declarations
  - count number of goto statements
  - determine the methods with more than 25 lines of code
  - determine the methods with McCabe complexity larger than 3

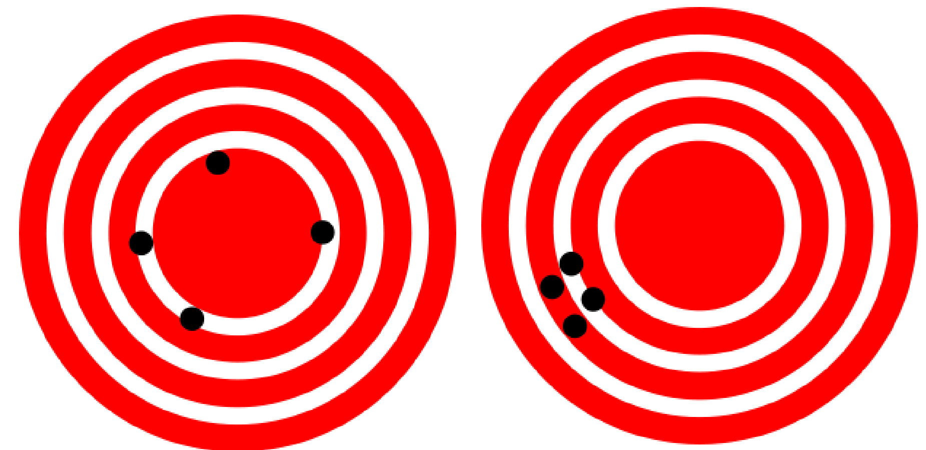
# Static versus Dynamic Analysis, 2

- For other analysis problems, static analysis can only provide a conservative approximation:
  - call graph construction
  - dead code determination
- Some language constructs hinder static analysis:
  - run-time method selection in Java
  - reflection in Java
  - pointer indirection in C
  - run-time execution of strings as code

# Intermezzo: Quality of analysis

- Binary classification
  - False/true positives/negatives
  - PPV: precision
  - TPR: recall
- Measurement
  - Precision vs Accuracy
  - Significant digits!
  - Units of measure!

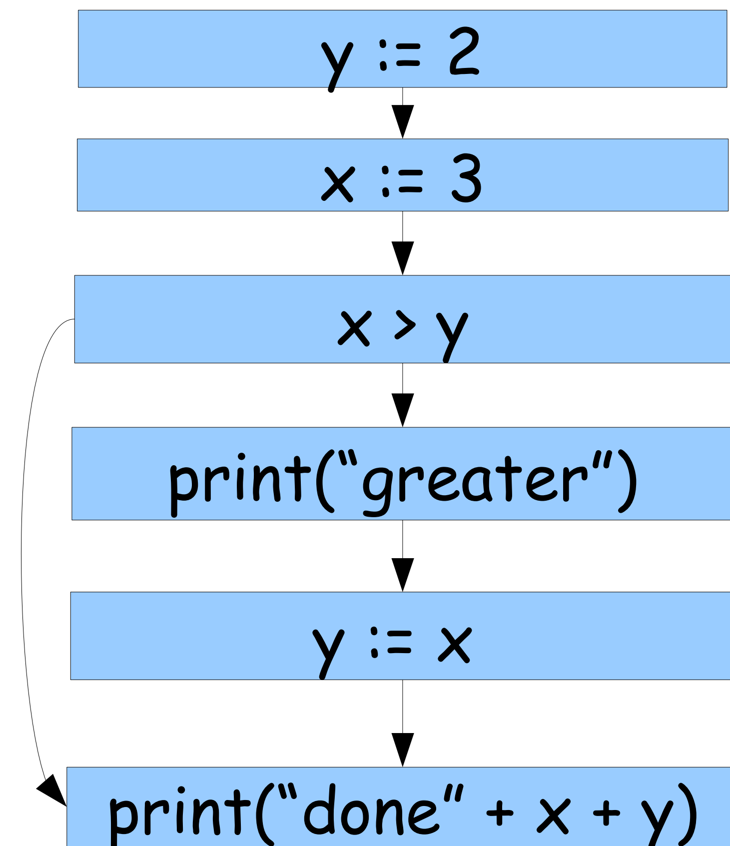


# Control Flow graph

- Connects statements in the order in which they may be executed

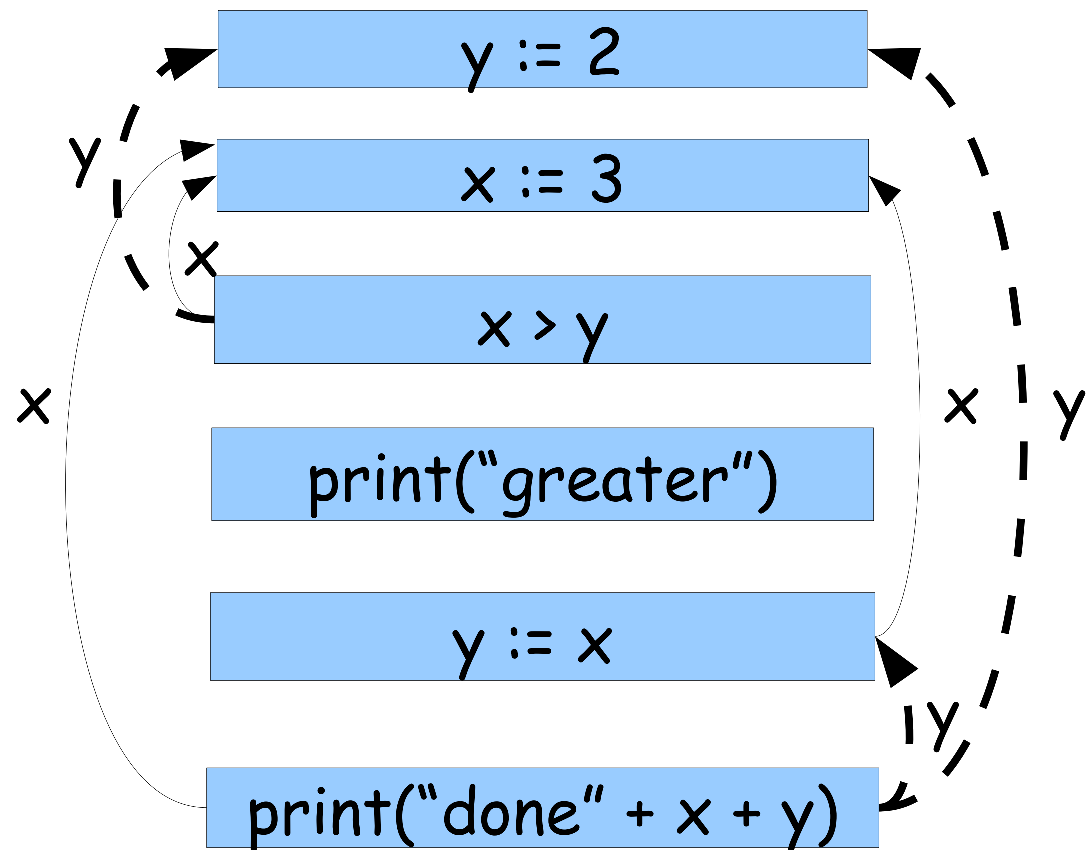
```
y := 2;
x := 3;
if x > y then
   print("greater");
   y := x
endif
print("done" + x + y)
```



# Data Flow graph

- Connects variable uses with their definitions

```
y := 2;
x := 3;
if x > y then
   print("greater");
   y := x
endif
print("done" + x + y)
```



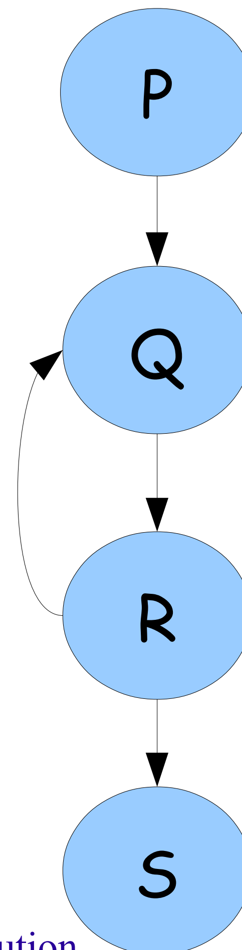
# Call Graph

- Connects procedure calls with their definitions

```
proc P { ... call Q ...}

proc Q { ... call R...}

proc R { ... call Q ...
         ... call S ... }
proc S { ... }
```

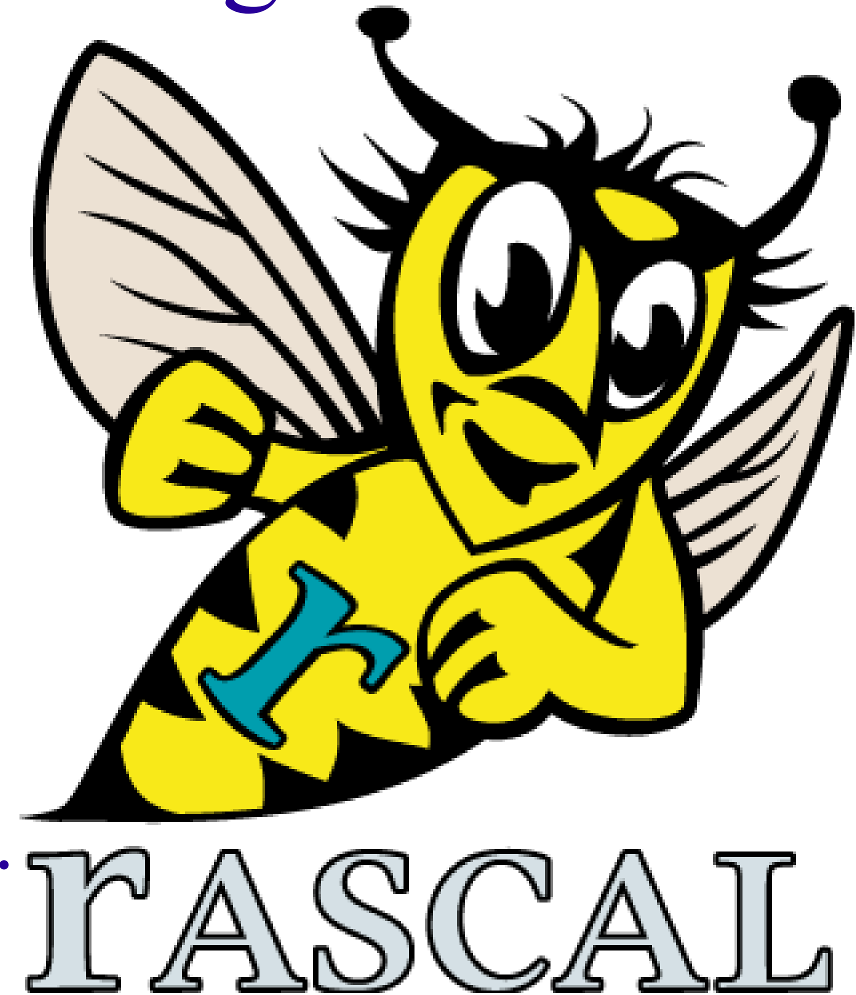


# Examples of Program Transformations

- Change the layout of the code according to standard rules
- Change method names
- Remove goto's
- Remove dead code
- Transform C to Java (very hard!)
- Migrate from some other (incompatible) library
- Migrate to another database system

# Meta programming

- Type-checkers
- Refactoring
- Source-to-source
- Reverse engineering
- Reengineering
- Documentation generation
- Mining version repositories…
- All in the Rascal domain



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# Resources

- Blackboard: blackboard.ic.uva.nl
- Course: 20122013.Software Evolution
- http://www.rascal-mpl.org
- www.acm.org/dl (ACM Digital Library)
- www.computer.org/portal/site/csdl (IEEE digital Library)
- Access to DLs is restricted (only via UvA).

# Now

- Coffee
- At 11:00 in G0.18 series 0
  - Installing and starting Eclipse + Rascal
  - Rascal tutor exploring
- Next Monday (here and in G0.18)
  - Joost Visser from SIG (here)
  - Rascal theory (here)
  - Rascal interactive course (G0.18)

# Take Home Messages

- Software Evolution is a real problem
- Software Maintenance is hard but interesting
- We designed Rascal for meta programming
- The lab is difficult but teaches you a lot
  - Metrics
  - Visualization
- The essay is important
  - Think of your thesis!