Lecture 6

Software Quality Measurements

Some materials are based on Fenton's book

Last lecture and tutorial …

Software Refactoring

- We showed the use of refactoring techniques on understanding software, improving its maintainability
- We explained the relationship between refactoring, tuning and restructuring
- Any questions related to design patterns and refactoring so far?
- ……
- The result of such improvements can be measured quantitatively

Today …

On Software Quality Measurements

1. What are measurements?
2. Quality attributes and their metrics
   - Performance metrics
   - Complexity metrics
3. How do you use these numbers?
   - Statistic Analysis to gain understanding on projects
   - Management: Monitoring the evolution of software development
4. Summary

References

N. Fenton and S. L. Pfleeger. “Software Metrics – A rigorous and practical approach”. International Thompson Computer Press. 1996

1. What are measurements?

- A relation of the real world is “reflected” in that of the math world
  - If A is taller than B, B is taller than C, then A is taller than C
- Preserve the relations in your metrics
- Software measurements
  - Software size?
    LOC
    LOC – comments
    LOC in Python vs. LOC in Fortran?

2. Quality that matters

- Company A beats company B, because of which reason do you think?
  (1) A deliver more features than B
  (2) A has larger market share
  (3) A deliver software with fewer bugs
  (4) A is cheaper
- Killer applications
  – Browser
  – Chips
  – Desktop
  – Operating System
  – Database Systems
- Andy Grove's story in his book "Only paranoid can survive"

A few more remarks

- Producing quality products has been identified as a key factor in the long term success (i.e. profitability) of organizations
- Quality doesn't happen by chance
- Quality control must be embedded into the process.
- The quality movement

What is software quality?

- Software quality is defined as
  - Conformance to explicitly stated functional [correctness] and non-functional requirements [performance, security, maintanability, usability, etc.] *i.e. Build the software described in the system Requirements and Specifications*
  - Conformance to explicitly documented development standards, *i.e. Build the software the right way*
  - Conformance to implicit characteristics that are expected of all professionally developed software, i.e. *Build software that meets the expectations of a reasonable person:* in law this is called the principle of *merchantability*

Managing Software Quality

1. Define what *quality* means for large software systems
2. Measure Quality of a complete or partial system
3. Devise actions to improve quality of the software
   - Process improvements
     - Process Performance improvements => Product Productivity improvements
   - Product improvements
4. Monitor Quality during development
   - Software Quality Assurance - a team devoted to encouraging and enforcing quality standards

Some quality attributes and metrics

- Performance
- Reliability
- Correctness
- Maintainability
- Security
- Interoperability
- Usability
- Extensibility
- Reusability
- -illities …

- Time, Space
- MTBF
- # Bugs / Size
- Size, Structureness
- Counter analysis
- Integration
- …
- …
- …
- …

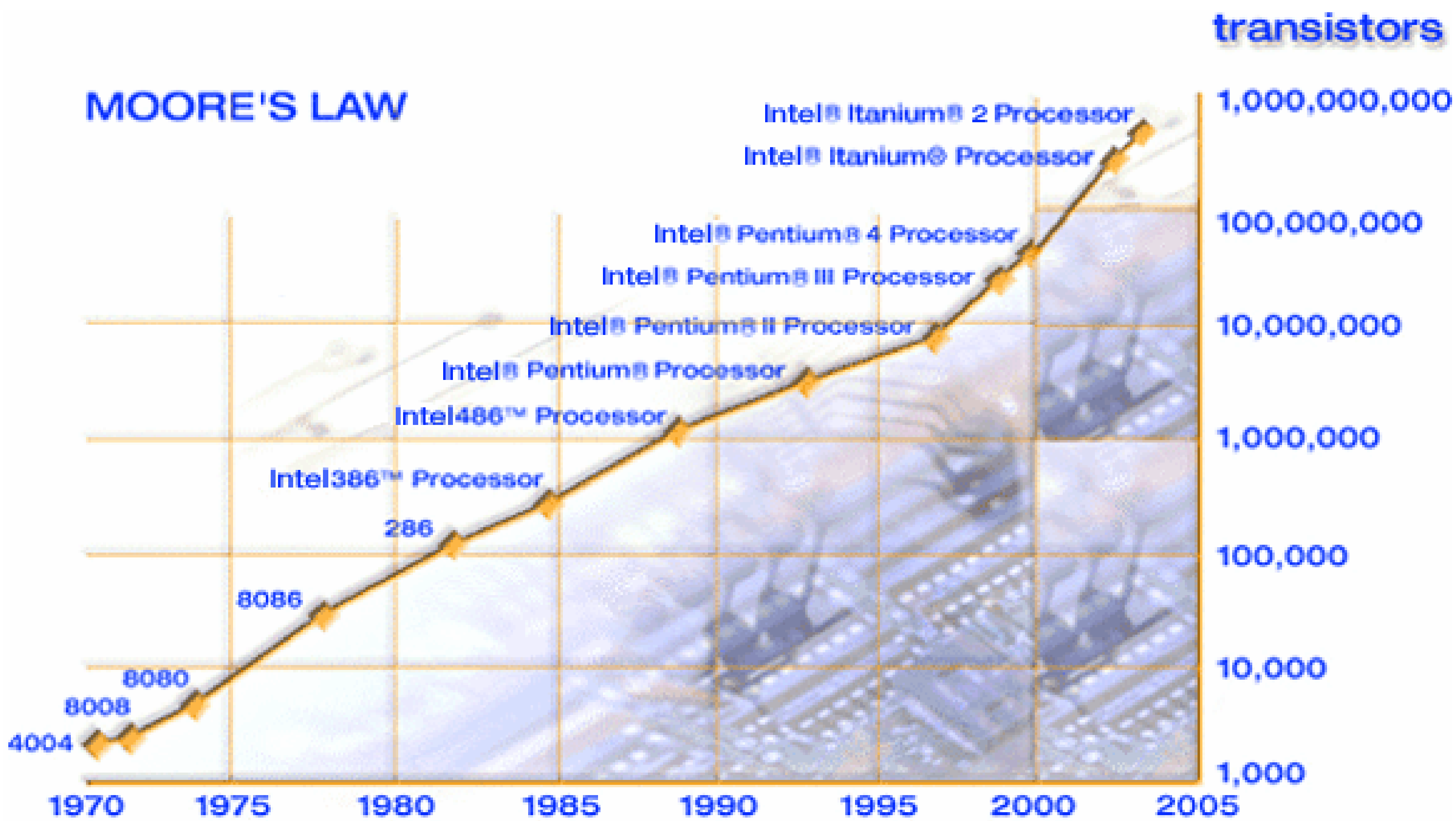
2.1 Performance

It is h/w bound, but can be improved by s/w

- Moore’s Law = 2x speedup every 18 months
- Software improvement for most cases are also possible (algorithms, optimizing compiler)
- It is sometimes more expensive to apply hardware improvements, sometimes more expensive to apply software improvements
- Advice: study the bottlenecks in your program using a profiler
  - parallelism
  - locality

2.1.1 Moore's law (Intel)

Itanium 2 processor	410,000,000
Cell processor	234,000,000



http://www.intel.com/research/silicon/mooreslaw.htm

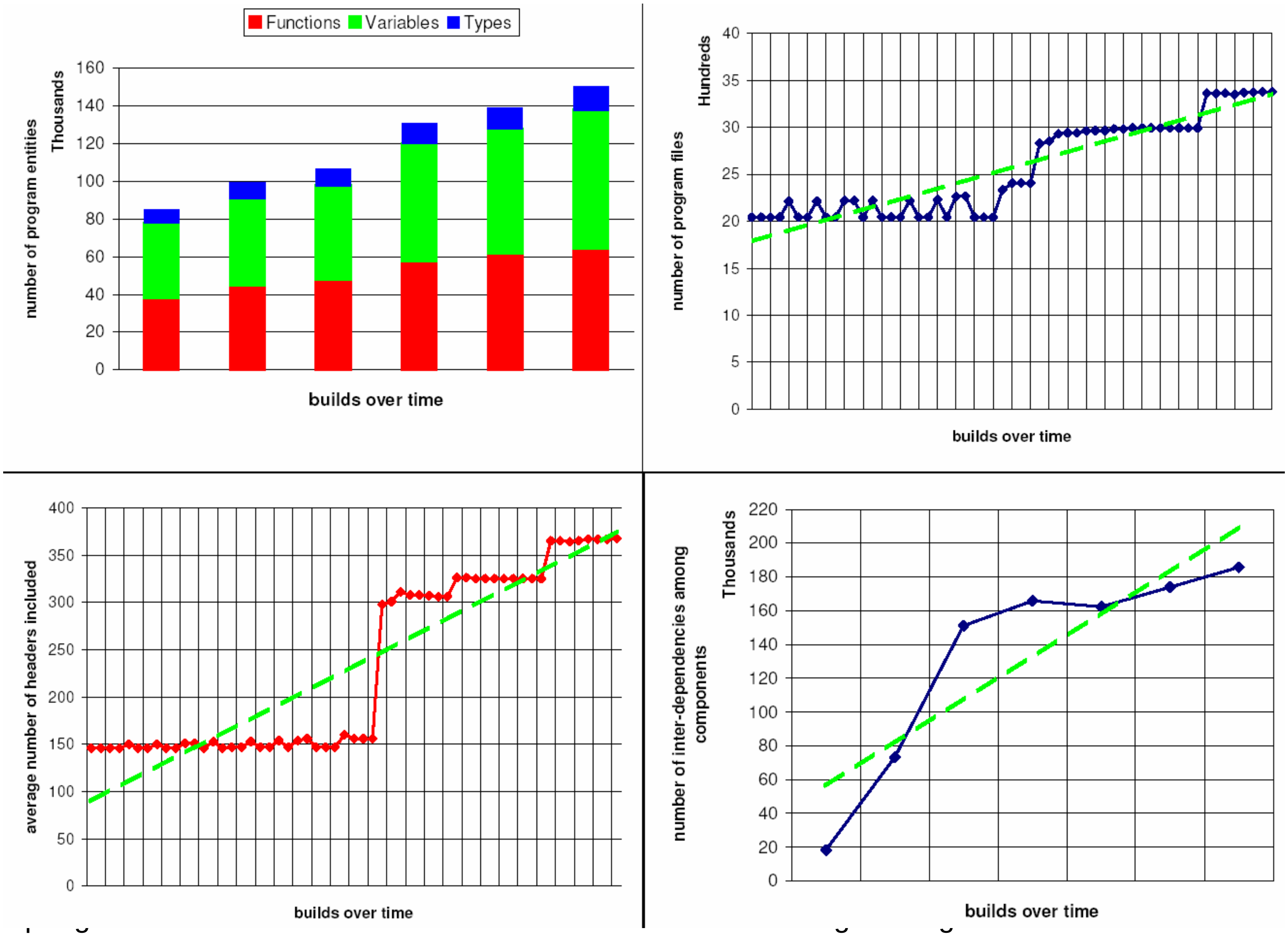
2.1.2 Performance metrics

- Time, in relation to the input size
  - CPU cycles, in relation to the input size
  - Cache misses, in relation to the input size
  - Network delay, system perf.
  - Network throughput, system perf.
- Space, in relation to the input size
  - Workload (memory footprint size), in relation to the input size
  - Network traffic, in relation to the input size

2.2 Software Complexity

- Software code base has increasing complexity – Lehman's Law #2.
- As a result, the code is harder to maintain
- This is the *central* theme of Software Engineering
- Well-understood complexity metrics
  - McCabe complexity
  - Halstead complexity
- Advices: refactoring or restructuring

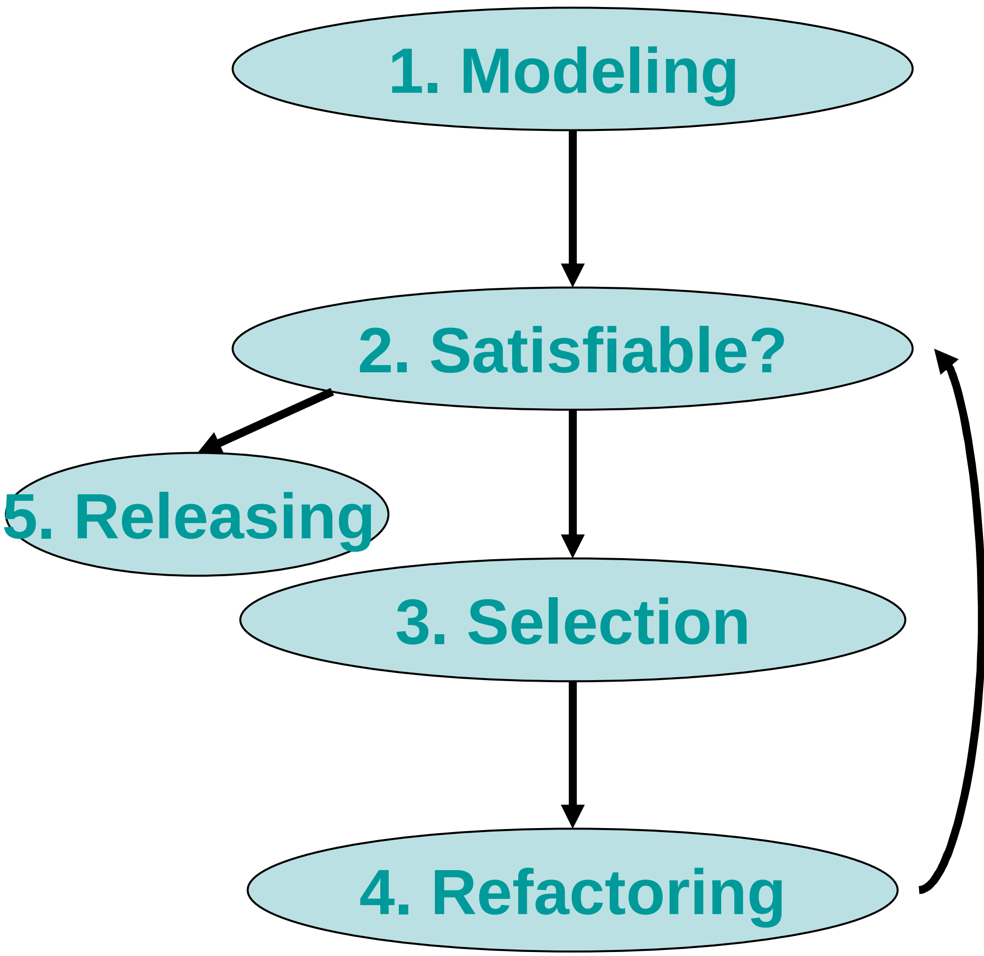
2.2.1 Lehman’s law on software complexity



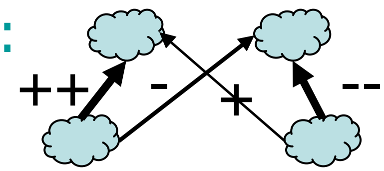
2.2.2 Complexity metrics

- Source size or compiled size
  - Lines of code (LOC)
  - McCabe's complexity
    $|V| + |E| - 2$
    for a control flow graph G=(V, E).
  - Halstead's Software Science metrics
    $(N_1 + N_2) \log (n_1 + n_2)$
    N_1 = operands, N_2 = operators
    n_1 = unique operands, n_2 = unique operators
- OO Software Metrics
  - Cohesion metrics in Packages, Classes, Methods
  - Coupling metrics in Packages, Classes, Methods

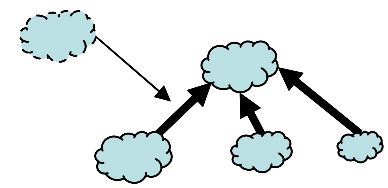
3. How to use them in software development process?



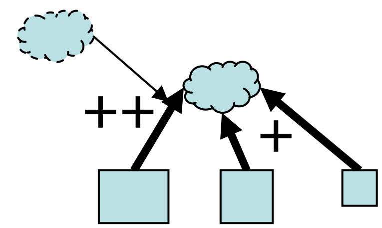
Quality soft-goal: intention [topic] taxonomy



Claim soft-goal: prioritization (bottleneck), metrics, constraints, rationale



Claim soft-goal: refactoring steps + label propagation



A toy example

- Matrix Multiplication

```
real*8 A(512,512),B(512,512),C(512,512)
do i = 1 , M
  do j = 1, L
    do k = 1, N
      C(i,k) = C(i,k) + A(i,j) * B(j,k)
```

- Quality goal: "*speedup the program 20x without sacrificing the code complexity 4x*"

Some restructuring examples
Loop unrolling

```
real*8 A(512,512),B(512,512),C(512,512)
do i = 1 , M
  do j = 1, L
    do k = 1, N, 4
      C(i,k) = C(i,k) + A(i,j) * B(j,k)
      C(i,k+1) = C(i,k+1) + A(i,j) * B(j,k+1)
      C(i,k+2) = C(i,k+2) + A(i,j) * B(j,k+2)
      C(i,k+3) = C(i,k+3) + A(i,j) * B(j,k+3)
```

Some restructuring examples
Loop tiling

```
do i = 1, M, B1
 do j = 1, L, B2
  do k = 1, N, B3
   do ib = i, min(i+B1, M)
    do jb = j, min(j+B2, L)
     do kb = k, min(k+B3, N)
      C(ib,kb) = C(ib,kb)+A(ib,jb)*B(jb,kb)
```

Some restructuring examples

Loop interchanging

```
real*8 A(512,512),B(512,512),C(512,512)
do k = 1, N
 do j = 1, L
  do i = 1 , M
   C(i,k) = C(i,k) + A(i,j) * B(j,k)
```

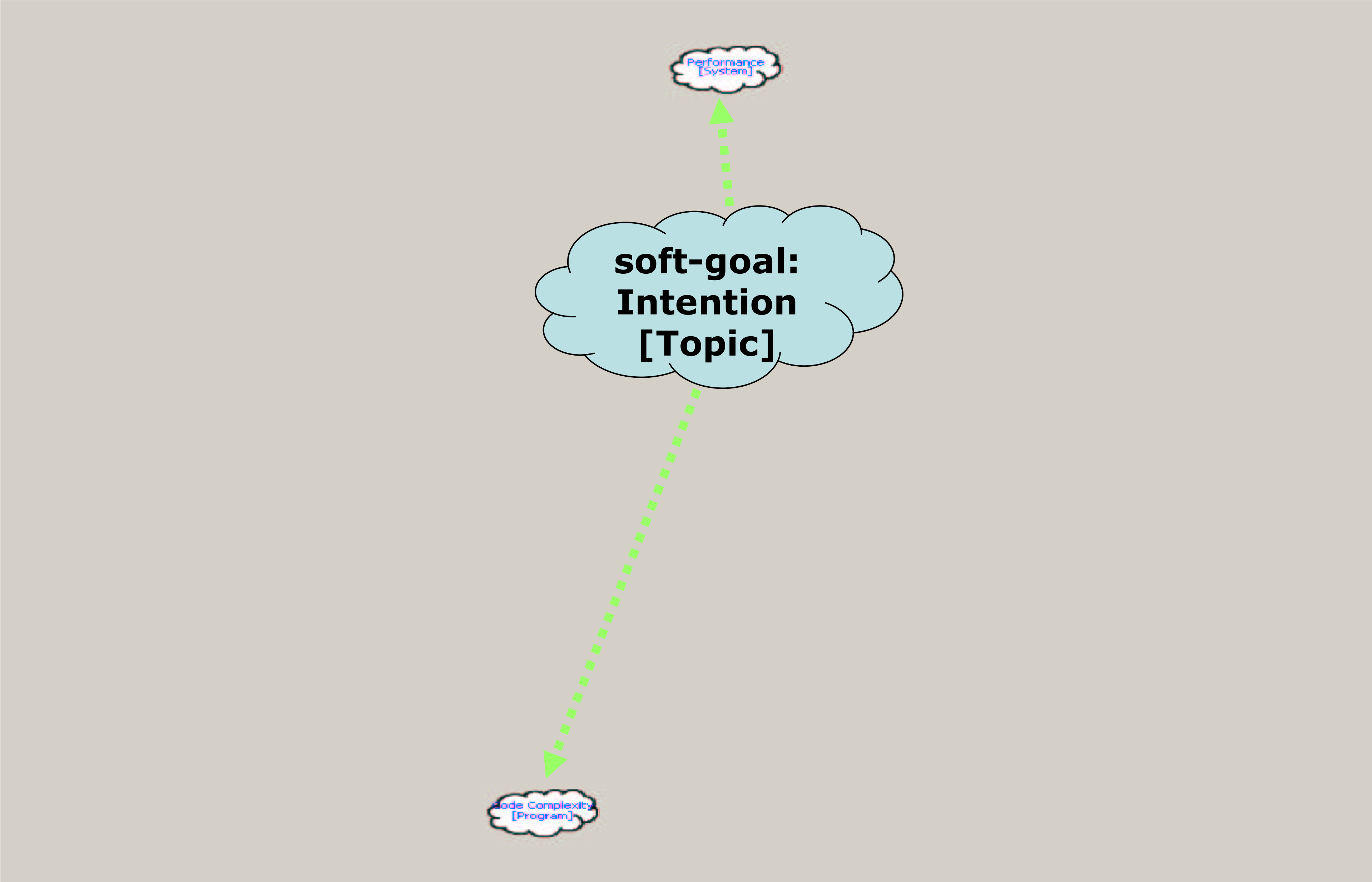
Some restructuring examples
Array padding

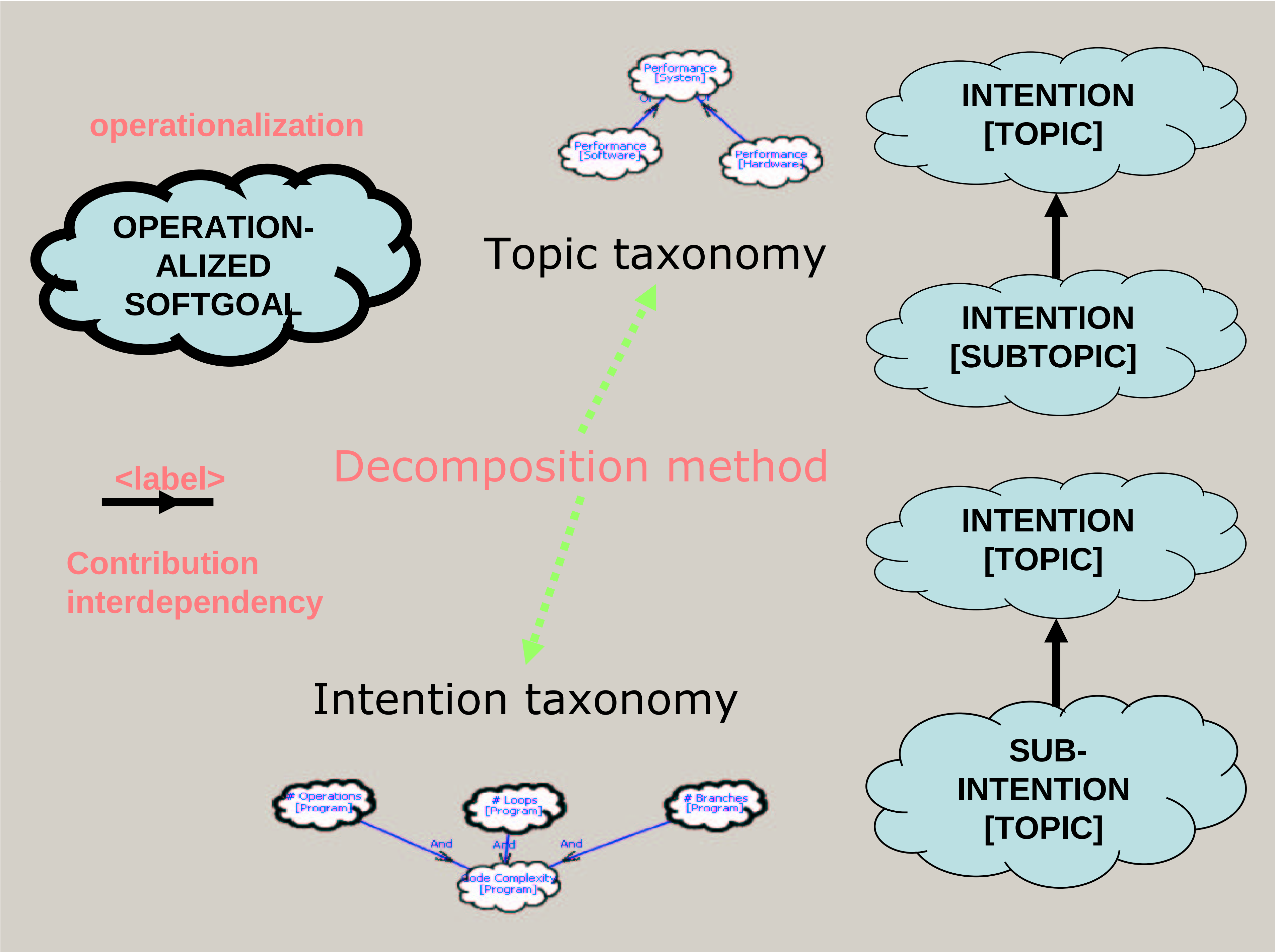
```
real*8 A(515,515),B(515,515),C(515,515)
do k = 1, N
 do j = 1, L
  do i = 1 , M
   C(i,k) = C(i,k) + A(i,j) * B(j,k)
```

Problem

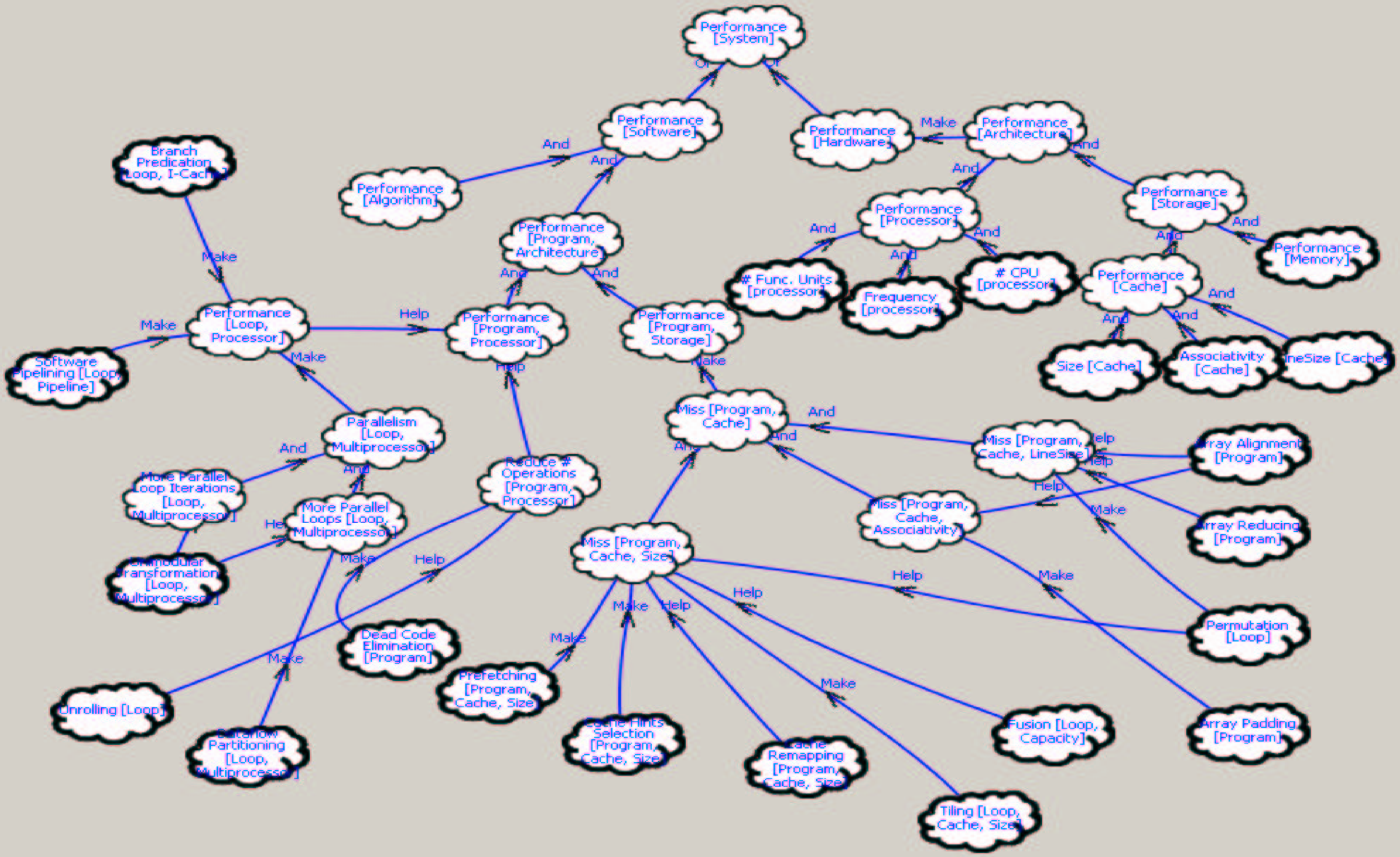
- Given the bunch of possible restructuring, which one is applicable, which one is profitable and which one is disastrous?
- How to represent and reuse the knowledge in many different applications?
- How to apply the knowledge to a new domain?
- Answer:
  Qualitatively and quantitatively reasoning

3.1 Qualitative reasoning

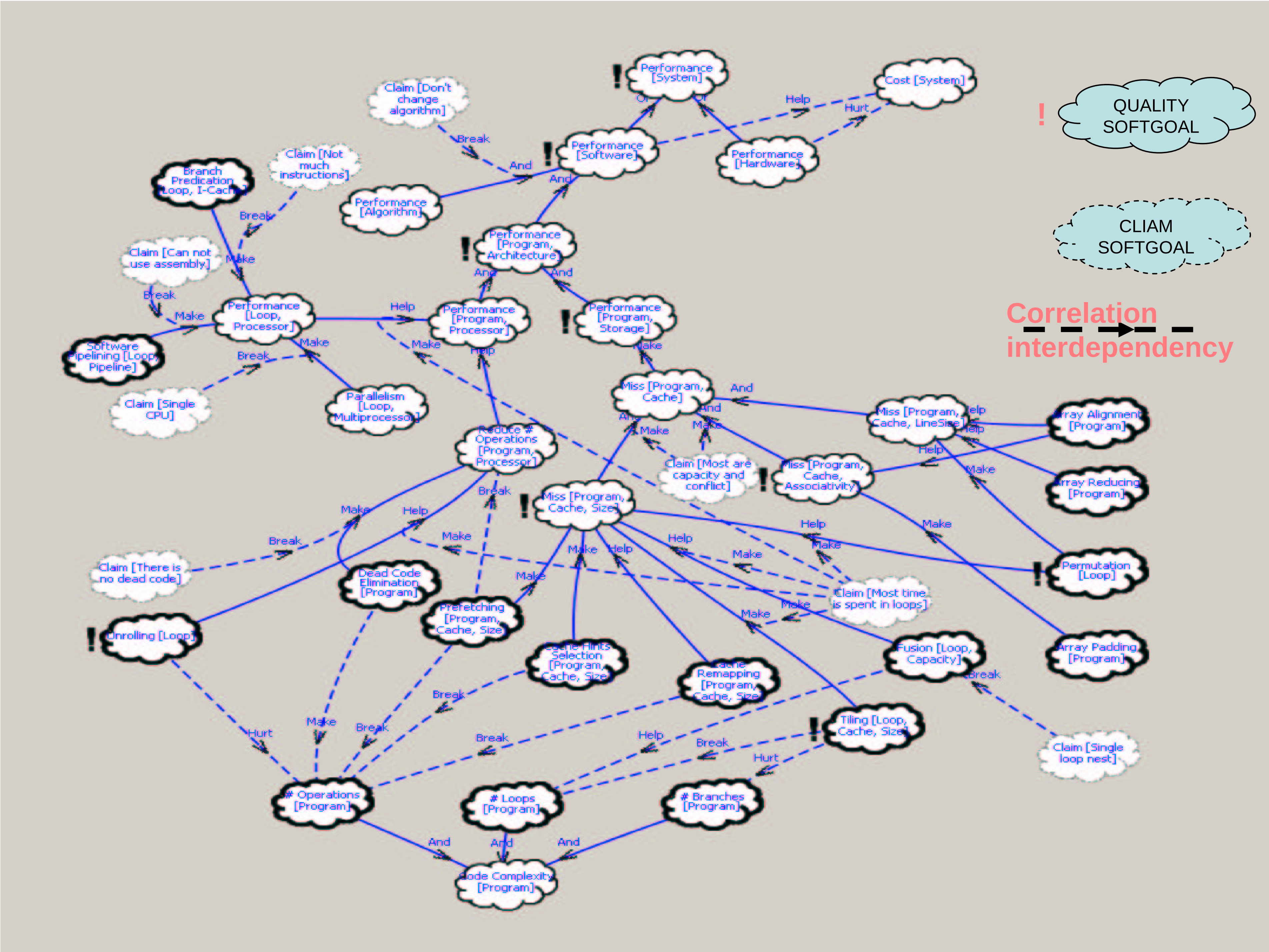


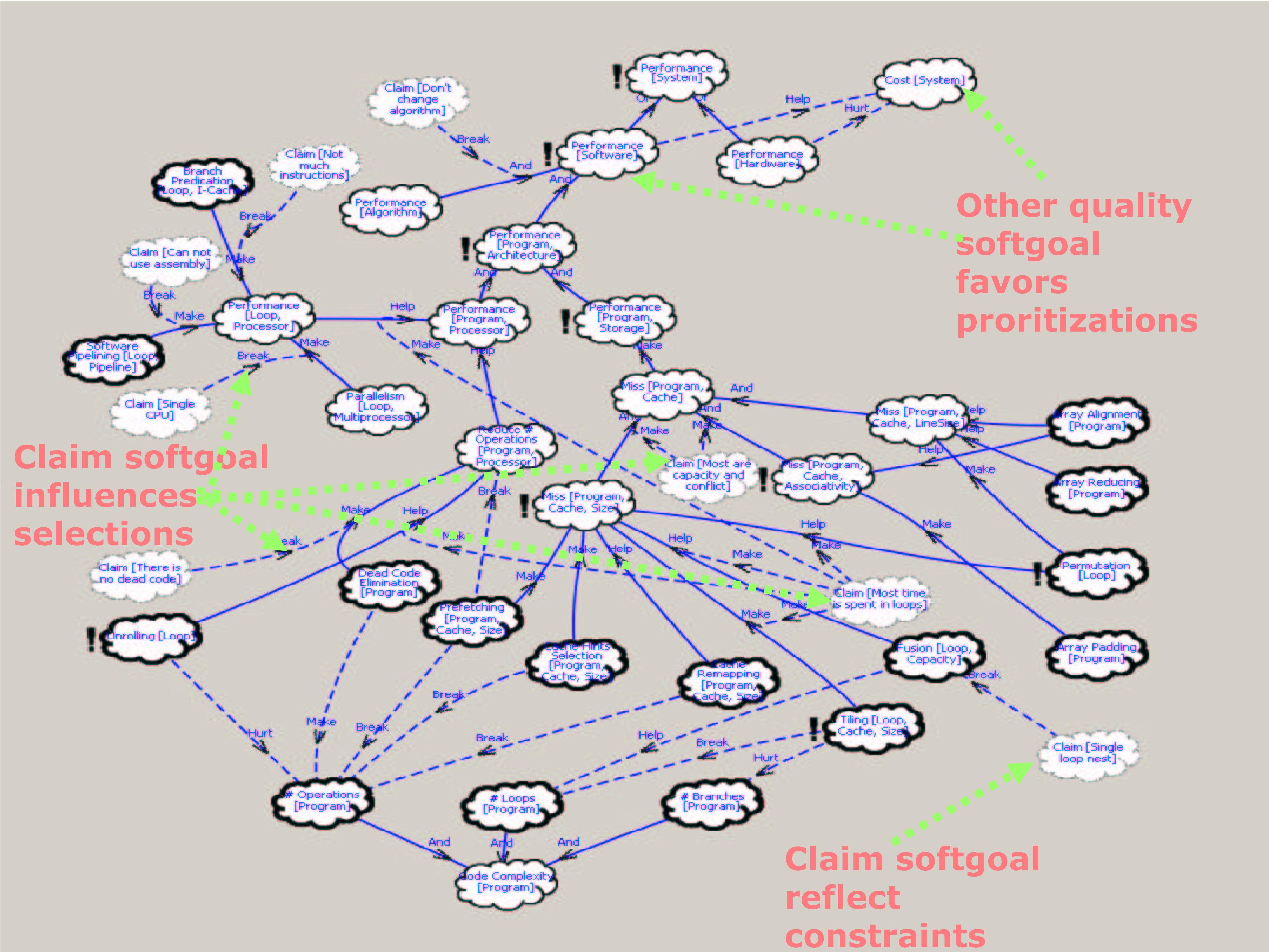


operationalization
OPERATION-
ALIZED
SOFTGOAL
Performance [System]
Performance [Software]
Performance [Hardware]
Topic taxonomy
Decomposition method
<label>
Contribution
interdependency
Intention taxonomy
Operations [Program]
Loops [Program]
Branches [Program]
And
Code Complexity [Program]
INTENTION
[TOPIC]
INTENTION
[SUBTOPIC]
INTENTION
[TOPIC]
SUB-
INTENTION
[TOPIC]



Decomposition of the performance soft-goal


Performance [System]
Cost [System]
QUALITY SOFTGOAL
CLIAM SOFTGOAL
Correlation interdependency
Claim [Don't change algorithm]
Performance [Software]
Performance [Hardware]
Claim [Not much instructions]
Branch Predication [Loop, I-Cache]
Performance [Algorithm]
Performance [Program, Architecture]
Claim [Can not use assembly]
Performance [Loop, Processor]
Performance [Program, Processor]
Performance [Program, Storage]
Software Pipelining [Loop, Pipeline]
Claim [Single CPU]
Parallelism [Loop, Multiprocessor]
Miss [Program, Cache]
Miss [Program, Cache, LineSize]
Array Alignment [Program]
Reduce # Operations [Program, Processor]
Claim [Most are capacity and conflict]
Miss [Program, Cache, Associativity]
Array Reducing [Program]
Miss [Program, Cache, Size]
Claim [There is no dead code]
Dead Code Elimination [Program]
Permutation [Loop]
Claim [Most time is spent in loops]
Unrolling [Loop]
Prefetching [Program, Cache, Size]
Cache Hints Selection [Program, Cache, Size]
Cache Remapping [Program, Cache, Size]
Fusion [Loop, Capacity]
Array Padding [Program]
Tiling [Loop, Cache, Size]
Claim [Single loop nest]
Operations [Program]
Loops [Program]
Branches [Program]
Code Complexity [Program]
Or
Help
Hurt
Break
And
Make



Performance [System]
Cost [System]
Claim [Don't change algorithm]
Performance [Software]
Performance [Hardware]
Claim [Not much instructions]
Branch Predication [Loop, I-Cache]
Performance [Algorithm]
Performance [Program, Architecture]
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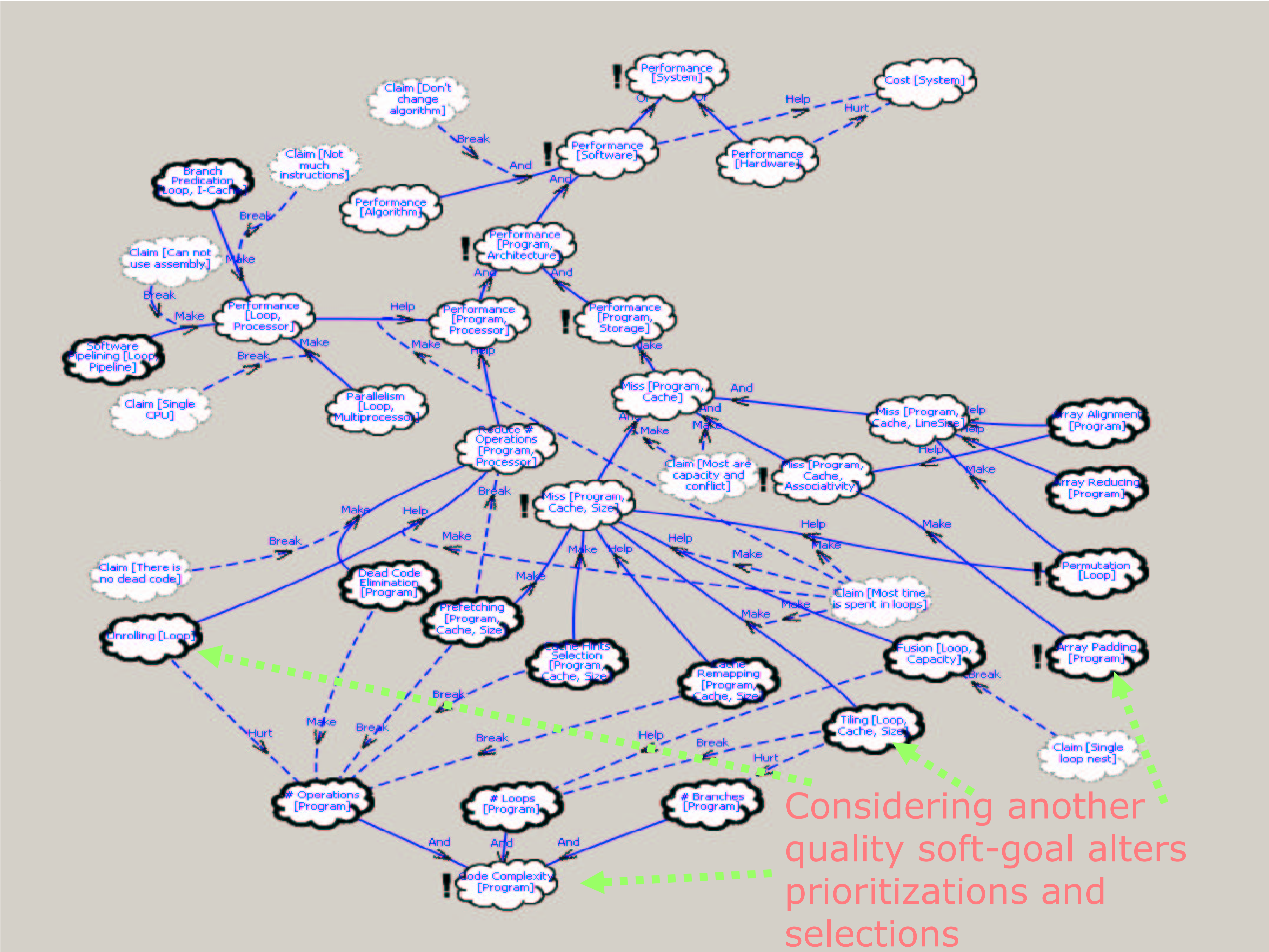
Other quality softgoal favors proritizations
Claim softgoal influences selections
Claim softgoal reflect constraints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Cost [System]
Claim [Don't change algorithm]
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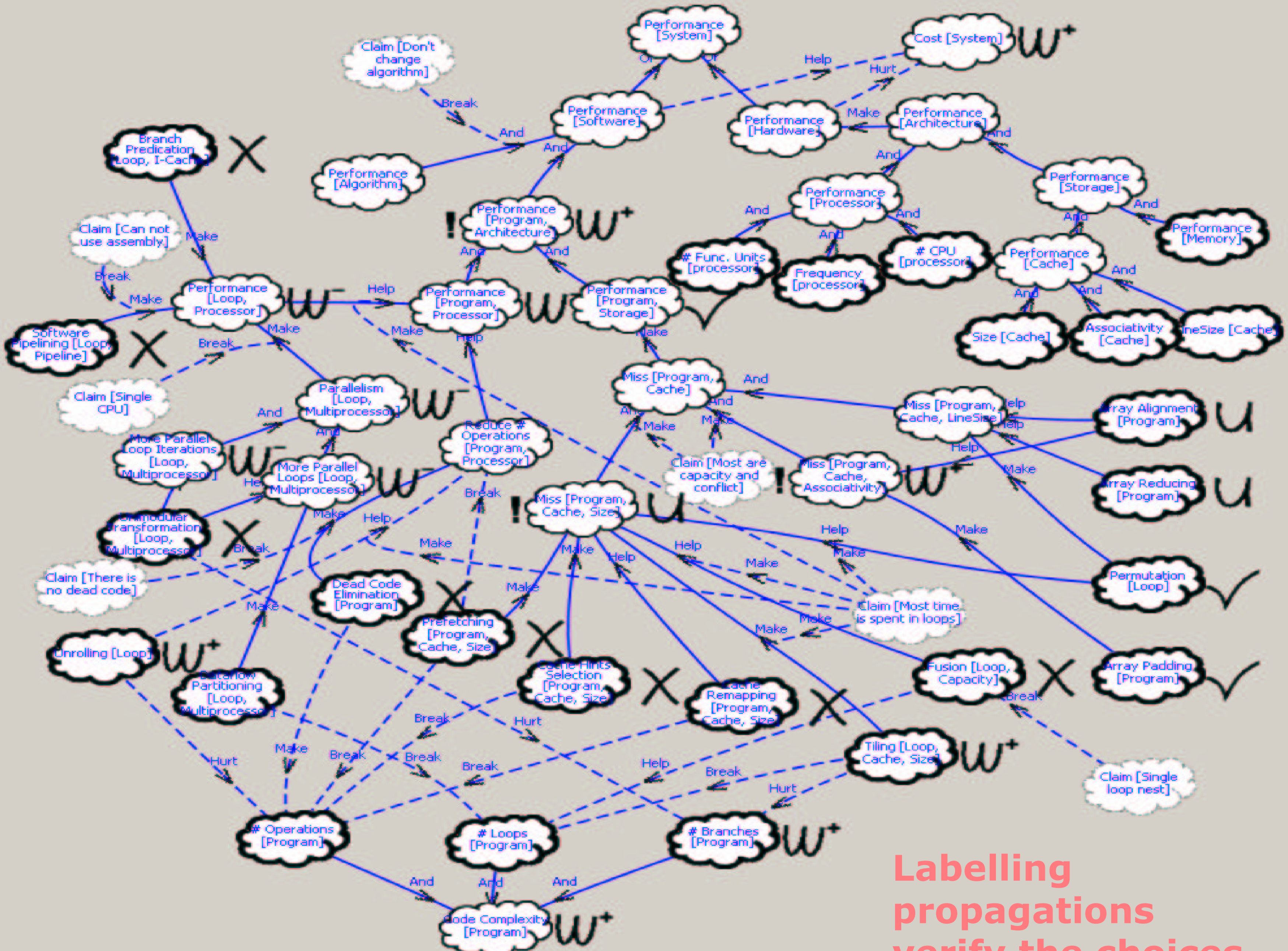
Branches [Program]
Code Complexity [Program]
Considering another quality soft-goal alters prioritizations and selections



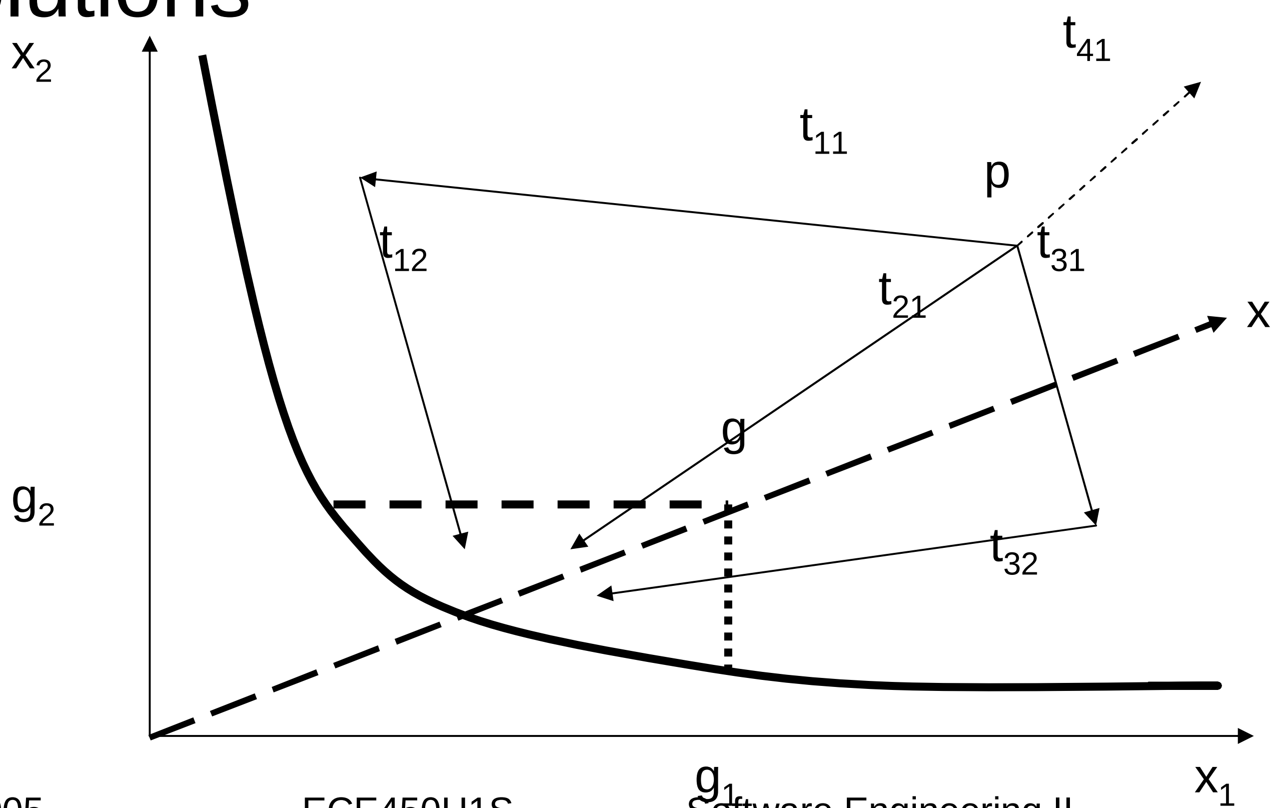
Labelling propagations verify the choices

Some remarks

- Each operationalization (thick nodes) is a restructuring (transformation) technique
- They contribute differently to their parent goals. If you do not have the subject (input), these rules generally encode the experiences
- You must collect data to quantitatively fine-tune the goal model

3.2 Quantitative reasoning

- When multiple criteria is concerned, the pareto curve defines the “optimal” solutions



Data collection

Experiment environment

- Hardware: Intel 1.2GHz Pentium 4 processor, with L1 cache (size=8KB, line=64 bytes, associativity=4), L2 cache (size=512KB, line=32 bytes, associativity=8).
- Tools: Datrix for measuring code complexity, VTune for measuring performance through hardware counters

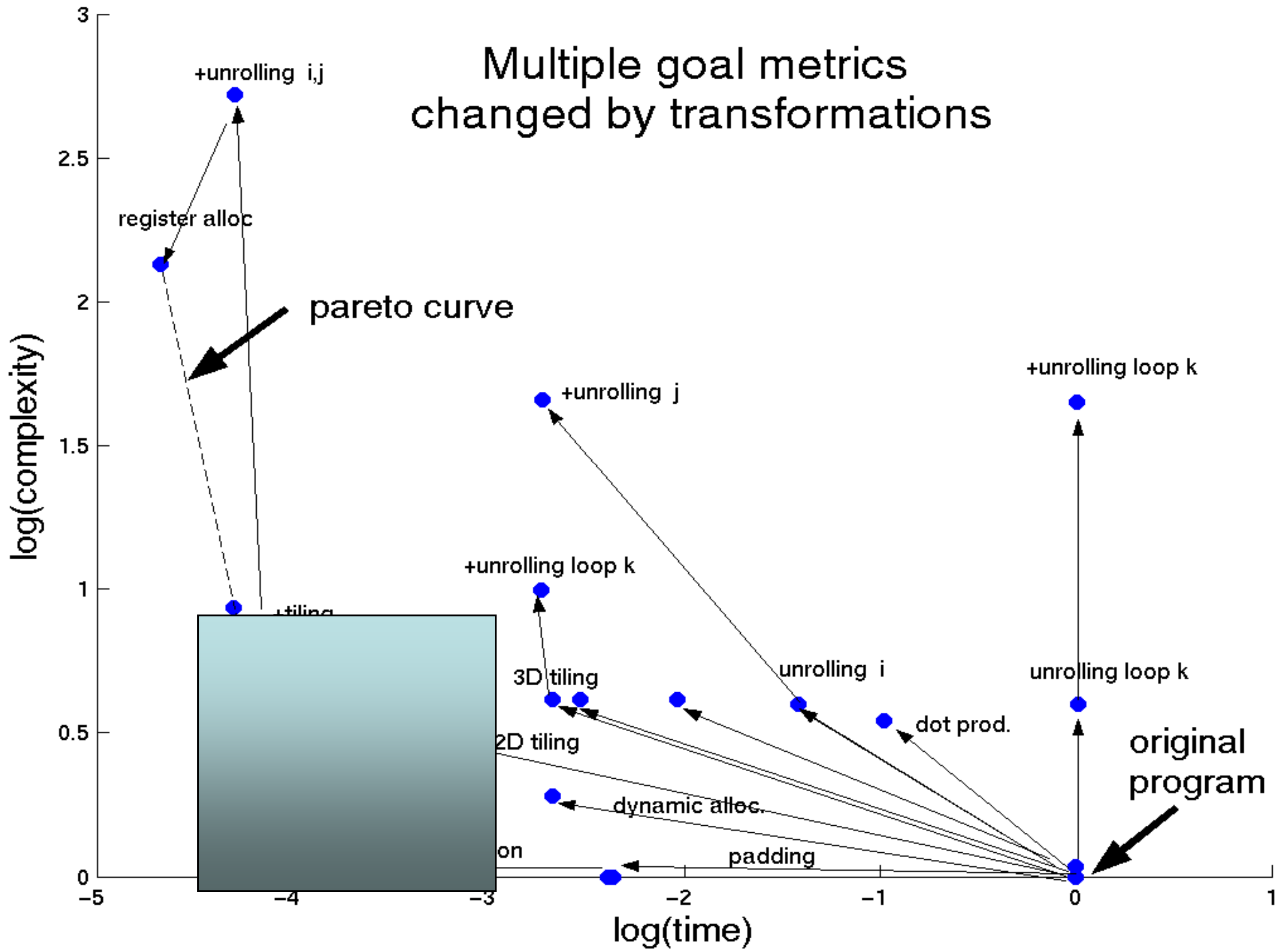
Metrics

- Time index = clockticks(t(p)) / clockticks(p)
- Complexity index = complexity(t(p))/complexity(p) where complexity(p) =
  v(g) ratio + length ratio + volume ratio
- ratio = (metric – $metric_{min}$) / ($metric_{max}$- $metric_{min}$)
- V(G) metric = e – n + 2
  length metric = (N_1+N_2)
  Volume metric = (N_1+N_2) $\log_2$ (n_1+n_2)
- e is the number of edges, n is the number of nodes in the control flow graph
  N_1 = number of operators
  N_2 = number of operands
  n_1 =number of unique operators
  n_2 = number of unique operands

Data gathered

R	time (sec.)	CPI	L1 (10^6)	L2 (10^6)	V (G)	len-gth	vol-ume
1	63.91	64.9	257.9	185.5	4	96	462
2	19.06	20.4	78.6	71.8	4	235	1164
3	4.92	3.36	307.8	1.7	7	185	964
4	1.54	1.33	129.1	47.8	4	96	462
5	5.45	6.30	265.6	12.5	4	96	462
6	1.11	1.23	123.9	44.8	4	96	462
7	3.30	4.28	324.1	2.1	7	312	1682
8	0.89	0.89	81.3	3.0	7	312	1682
...							

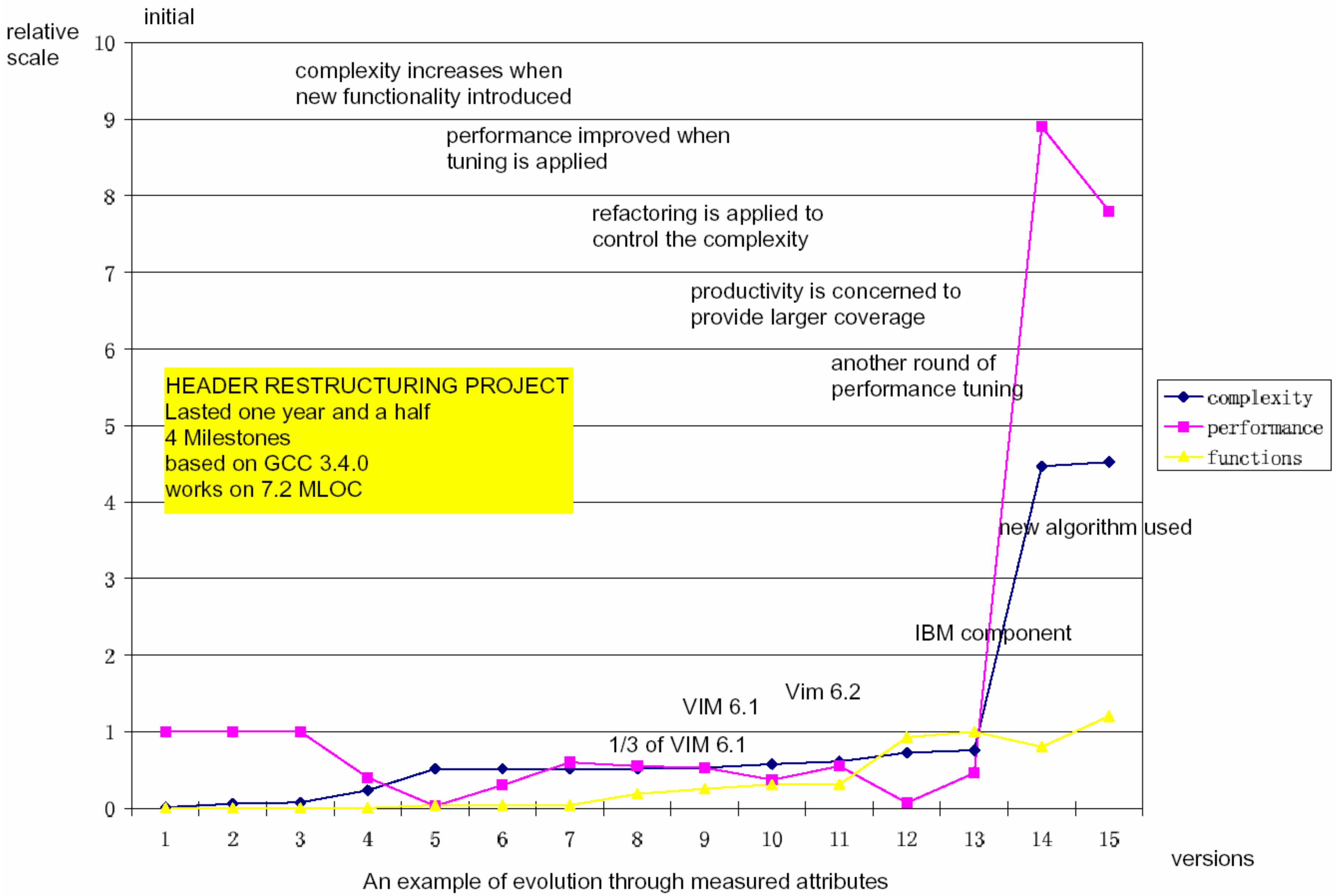
The multi-objective decision making process



A real example

- Header restructuring project
- Considered one more metric: functionalities
- The experience show that using a new algorithm can dramatically improve the performance (! Moore’s law)
- Also refactoring techniques when applied can reduce the complexity (! Lehman’s law)

Header restructuring metrics



Your exercise

- Monitor the evolution of your software product by measuring its metrics
  - Statically:
    complexity metrics: LOC, Halstead, McCabe
  - Dynamically:
    Performance metrics: time (clockticks, #instructions), space (cache misses, L1 instruction, L1 data, L2 cache, etc., memory footprint)
- Decide on which is the urgent non-functional task

4. Summary

- The concepts of software measurements
- How to measure some quality metrics
- You need to know your software and manage it by numbers
- Through these numbers, you will know/improve your own capability too

Further readings

- N. Fenton and S. L. Pfleeger. *Software Metrics – A rigorous and practical approach*.1996
- M.M. Lehman. "Laws of software evolution revisited", *LNCS1126:108-120.*1996.
- H. Dayani-Fard et al. "Quality-based software release management", PhD, 2004.
- H. Dayani-Fard et al. "Improving the build architecture of C/C++ programs", FASE, 2005.
- Y. Yu et al. "Software refactoring guided by softgoals", *REFACE workshop in conjunction with WCRE'03*.

What's next …

- A Tutorial on software measuring tools
  - How to measure performance?
  - How to measure code complexity?
  - How to measure your code in Eclipse?