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Code Quality from the Programmer's Perspective

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Two perspectives on code quality

Does the software correctly implements requirements? Is it easy to use? Does it crash?

How is the code organized? Where is <some> functionality implemented?

External (user's): *what?*

Internal (programmer's): *how?*

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User's frustration

- "after clicking all options and navigating all menus I still cannot find out how to achieve <this>"
- "why do I get this error message? I did nothing wrong – stupid software!"

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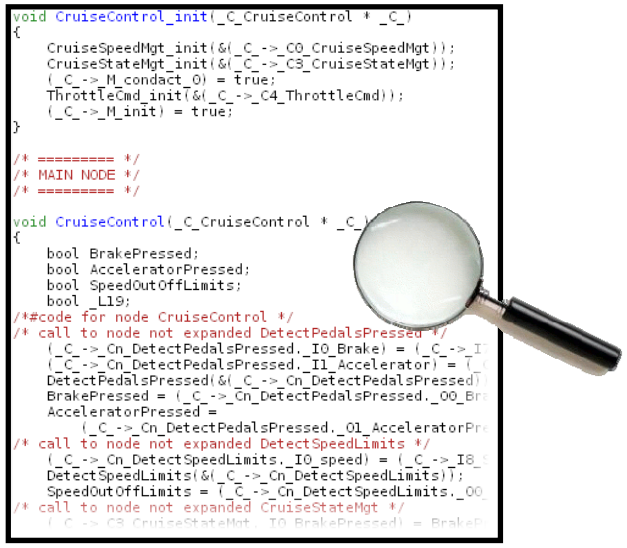
Programmer's frustration



```
void CruiseControl_init(_C_CruiseControl * _C_)
{
    CruiseSpeedMgt_init(&(_C_->_C0_CruiseSpeedMgt));
    CruiseStateMgt_init(&(_C_->_C3_CruiseStateMgt));
    (_C_->_M_condact_0) = true;
    ThrottleCmd_init(&(_C_->_C4_ThrottleCmd));
    (_C_->_M_init) = true;
}

/* ========= */
/* MAIN NODE */
/* ========= */

void CruiseControl(_C_CruiseControl * _C_
{
    bool BrakePressed;
    bool AcceleratorPressed;
    bool SpeedOutOffLimits;
    bool _L19;
/*#code for node CruiseControl */
/* call to node not expanded DetectPedalsPressed */
    (_C_->_Cn_DetectPedalsPressed._I0_Brake) = (_C_->_I
    (_C_->_Cn_DetectPedalsPressed._I1_Accelerator) = (_
    DetectPedalsPressed(&(_C_->_Cn_DetectPedalsPressed
    BrakePressed = (_C_->_Cn_DetectPedalsPressed._O0_Br
    AcceleratorPressed =
        (_C_->_Cn_DetectPedalsPressed._O1_AcceleratorPr
/* call to node not expanded DetectSpeedLimits */
    (_C_->_Cn_DetectSpeedLimits._I0_speed) = (_C_->_I8_
    DetectSpeedLimits(&(_C_->_Cn_DetectSpeedLimits));
    SpeedOutOffLimits = (_C_->_Cn_DetectSpeedLimits._O0_
/* call to node not expanded CruiseStateMgt */
    (_C_->_C3_CruiseStateMgt._I0_BrakePressed) = BrakeP
```

- "I have to add this function, but it's impossible to find a single place where the addition should go in the intricate code structure"
- "the program produces the wrong output, but after several hours browsing the code I cannot identify which statements are guilty"

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Industrial context

- Customer's needs and domain are only partially known.
- There is little time to improve code structure and internal quality.
- Most quality improvement effort goes in checking the implementation against the requirements, little goes on internal quality improvement (no time available for that).

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Open source context

- Users and developers are often the same persons.
- Domain and requirements are well known, so they need no explicit model.
- Many developers are supposed to contribute, so the code should be easy to read and modify.
- Code inspections happen all the time.

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What about physics software?

- Developers are typically users.
- Domain is perfectly known.
- Many contributors and advanced users are spread all over the world.
- Hence, internal quality is probably the major quality goal; external quality descends quite “naturally”.

A Large Ion Collider Experiment

European Organisation for Nuclear Research

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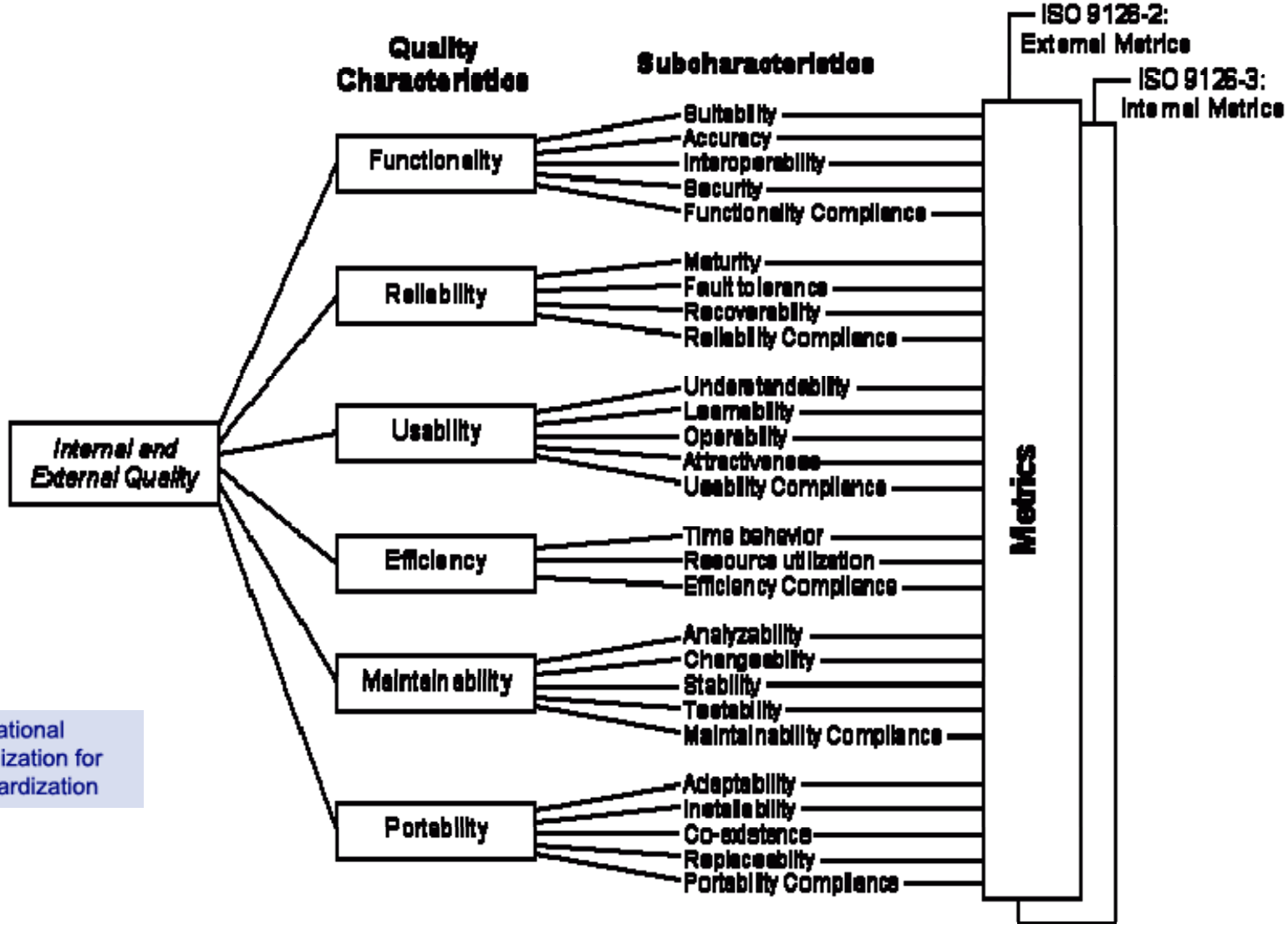
Quality models (ISO 9126)



ISO International Organization for Standardization

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Internal code quality

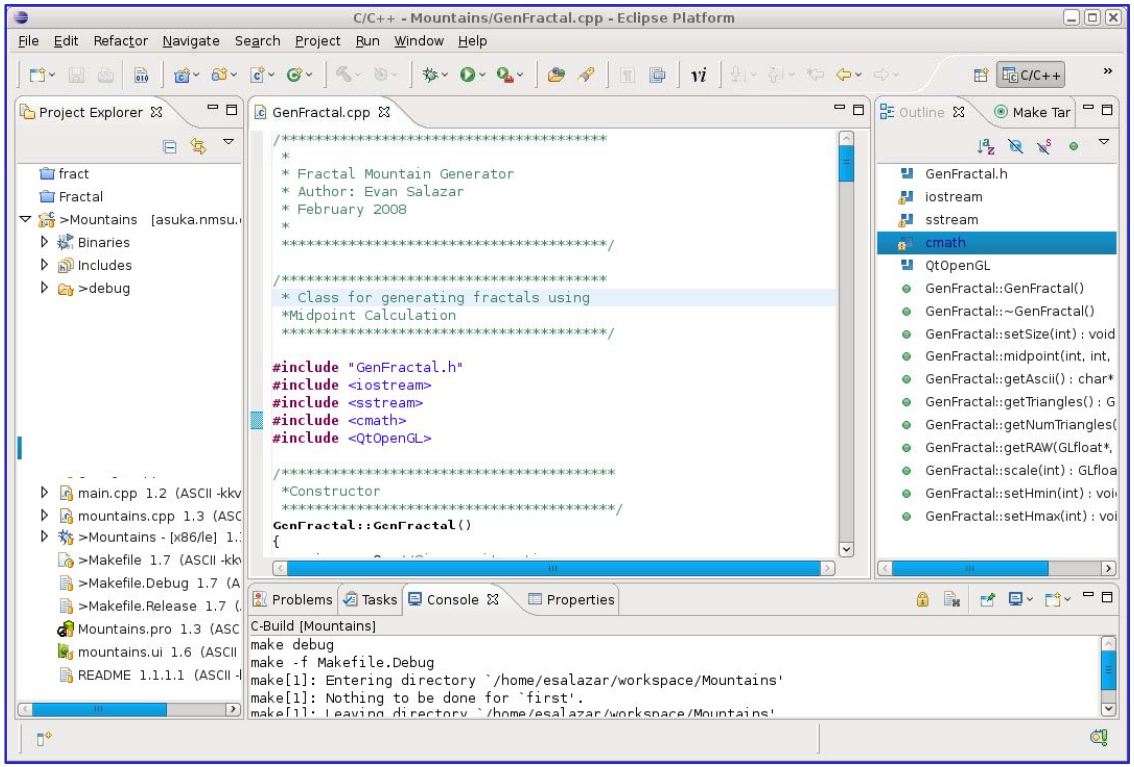
- **Metrics**: coupling, cohesion and other (DIT, CBM, LCM, etc.)
- **Code smells** and code refactoring: possibility to apply standard, known solutions (e.g., design patterns) and improvements.
- **Coding conventions**: coding rules, style rules, etc.

Internal quality still ignores the central role of **natural language** in programs.

Programmer's weapons

Let us consider the programmer's perspective, when executing a typical programming task (add function, fix bug, etc.):

- **Text processing**: Grep or CTRL-F.
- **IDE navigation**: Structure view, call graph, debugger, design diagrams, etc.



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Clues from natural language

- Available tools do not take advantage of natural language clues.
- Quality of natural language in the code is currently neglected.

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Is this one the class you are looking for?

```
public class T01<T02,T03> extends T04<T02,T03>
  implements T05<T02,T03>, T06, T07 {

  public T03 m01(T02 x01, T03 x02) {
    if (x01 == null)
      return m02(x02);
    int x03 = m03(x01.m04());
    int x04 = m05(x03, x05.x06);
    for (T08<T02,T03> x07 = x08[x04]; x07 != null; x07 = x07.x09) {
      T09 x10;
      if (x07.x11 == x03 && ((x10 = x07.x12) == x01 || x01.m06(x10))) {
        T03 x13 = x07.x14;
        x07.x14 = x02;
        x07.m07(this);
        return x13;
      }
    }
    x15++;
    m08(x03, x01, x02, x04);
    return null;
  }
}
```

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Is this one the class you are looking for?

```
public class HashMap<K,V> extends AbstractMap<K,V>
  implements Map<K,V>, Cloneable, Serializable {

  public V put(K key, V value) {
    if (key == null)
      return putForNullKey(value);
    int hash = hash(key.hashCode());
    int i = indexFor(hash, table.length);
    for (Entry<K,V> e = table[i]; e != null; e = e.next) {
      Object k;
      if (e.hash == hash && ((k = e.key) == key || key.equals(k))) {
        V oldValue = e.value;
        e.value = value;
        e.recordAccess(this);
        return oldValue;
      }
    }
    modCount++;
    addEntry(hash, key, value, i);
    return null;
  }
}
```

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Self-documenting identifiers

Good identifiers:

- provide concise clues on the semantics of labeled entities;
- save programmers from reading the entire code segment;
- speed up knowledge acquisition;
- support program understanding (code queries, grep, etc.).

Corollary: When we teach programming, we should never let our students use names such as `foo` or `bar` (`pippo`, `pluto`) for any program entity.

To some extent, we know a lot about the structure of a program.

What do we know about the lexicon of programs?

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Our experience with CERN/Alice

- Developed RuleChecker in 1999; NewRuleChecker delivered in 2008, based on srcML.
- Verified internal quality properties about structure, code organization, style, etc.
- Identified sub-systems with poor internal quality and enforced their improvement.
- Programmers felt the eye of RuleChecker over their code, so they probably paid more attention to coding rules and guidelines.

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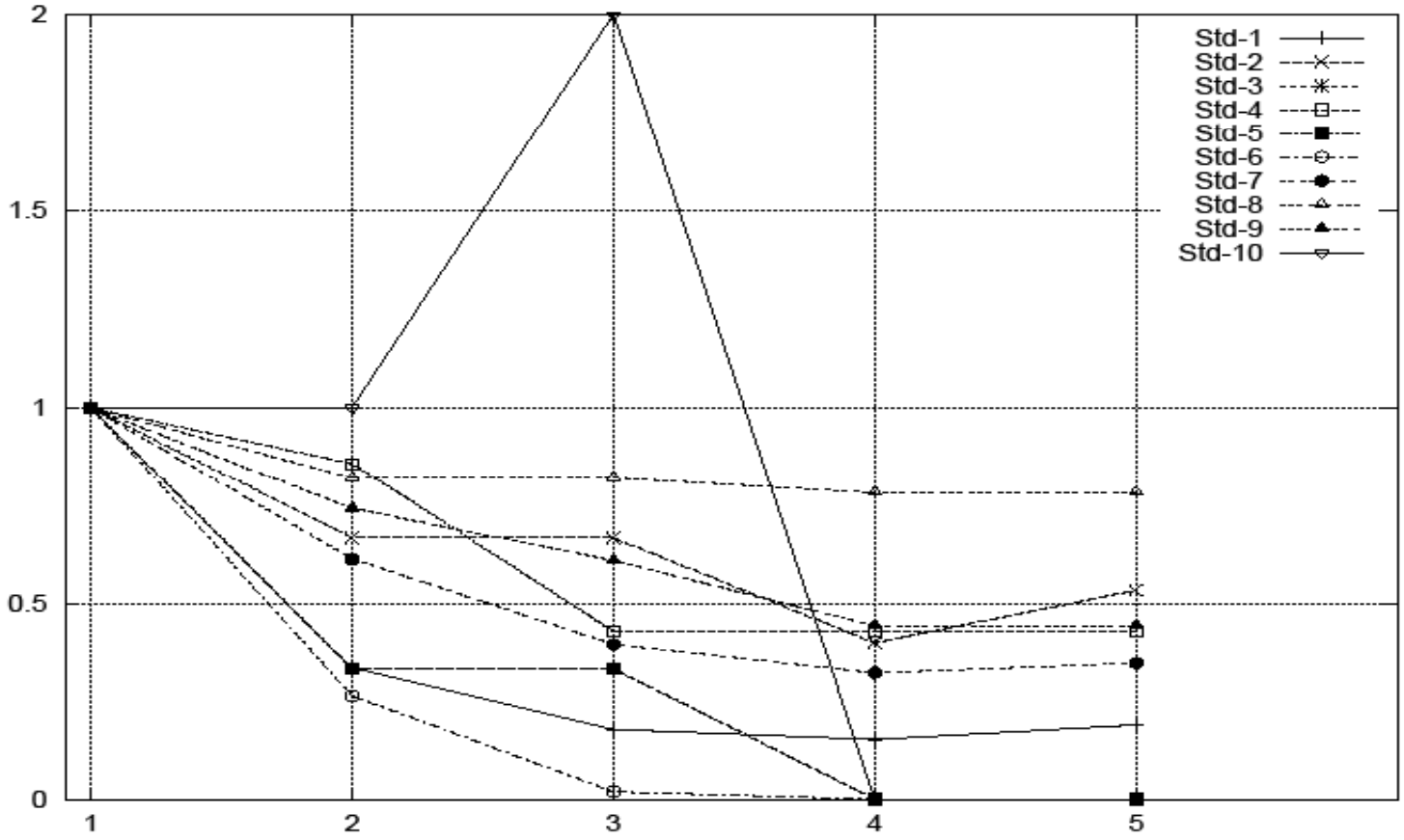
Naming rules



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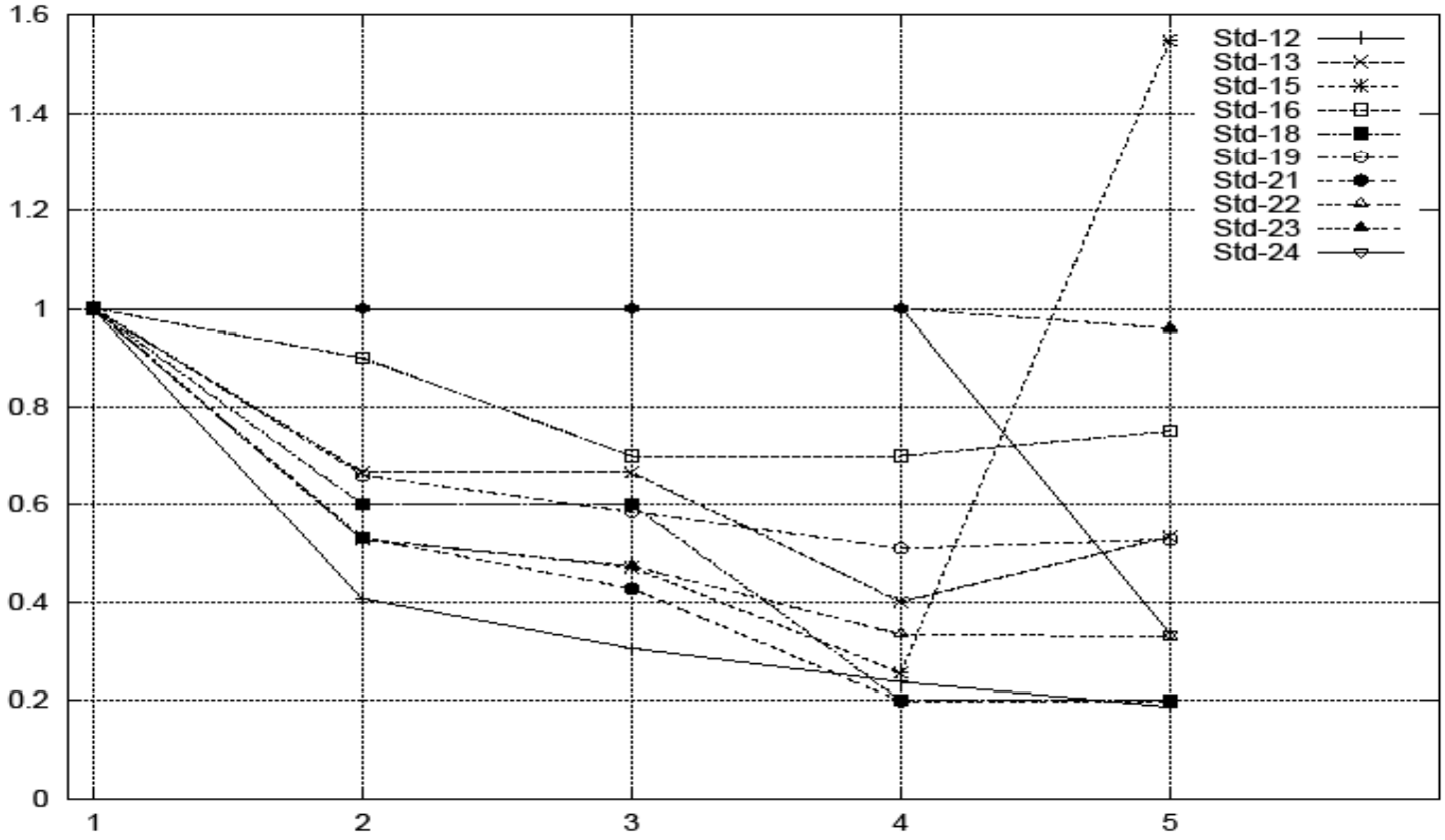
Coding rules



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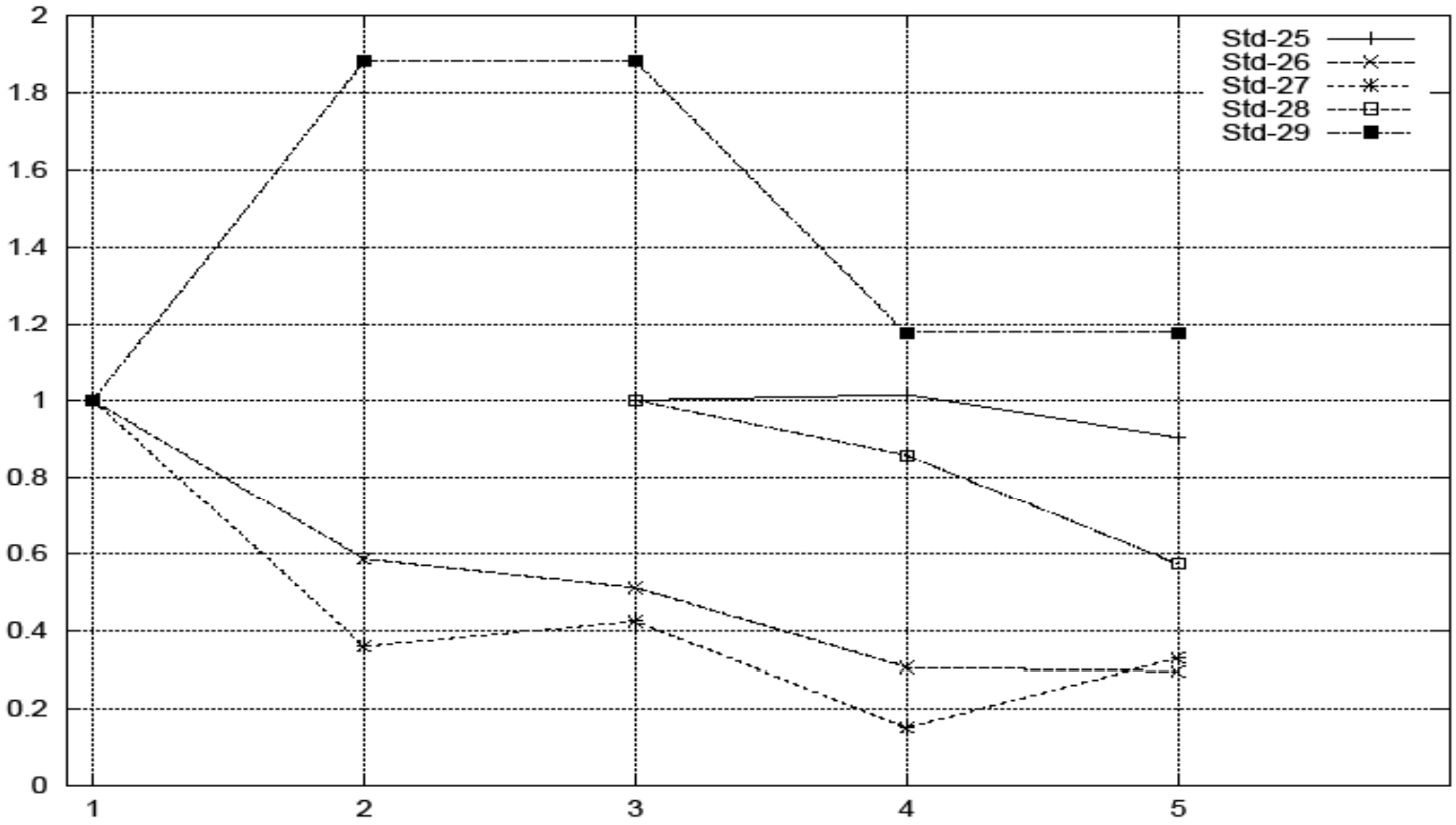
Style rules



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Results

- Successfully improved internal quality indicators (metrics, code smells, coding conventions), mostly related to the internal code structure.
- Not yet considered the quality of the informal information embedded in the code: quality of programmer's lexicon and its consistent usage.

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Empirical studies on CERN/Alice code

- **Empirical study #1:** Stability of lexicon, compared to structure (ICSM 2007).
- **Empirical study #2:** Delta analysis: why and how is the lexicon evolved? (paper under review, 2008).

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Empirical Study #1

RQ1: How does the stability of the lexicon of identifiers compare to the stability of the program structure as the program evolves?

RQ2: What is the frequency of changes to program entities (in particular renaming) due to identifier refactoring?

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Stability metrics

For leaf entities, **cosine similarity:**

StructSim(Ei, Ej) = <struct(Ei), struct(Ej)> / |struct(Ei)| |struct(Ej)|

LexicalSim(Ei, Ej) = <lexicon(Ei), lexicon(Ej)> / |lexicon(Ei)| |lexicon(Ej)|

Function
Name: put **Struct**: <10, 1, 2, 31, 0, 0, 24> **Lexicon**: <0, 0, 0, 1, 1, 1>
Function
Name: put' **Struct**: <11, 2, 1, 30, 0, 0, 22> **Lexicon**: <0, 0, 0, 1, 1, 1>

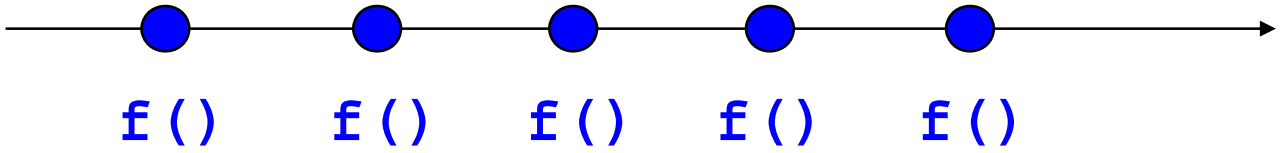
StructSim(put, put') = 0.998
LexicalSim(put, put') = 1

For container entities, **average similarity**

Similarity between corresponding entities in the history ► entity traceability required!

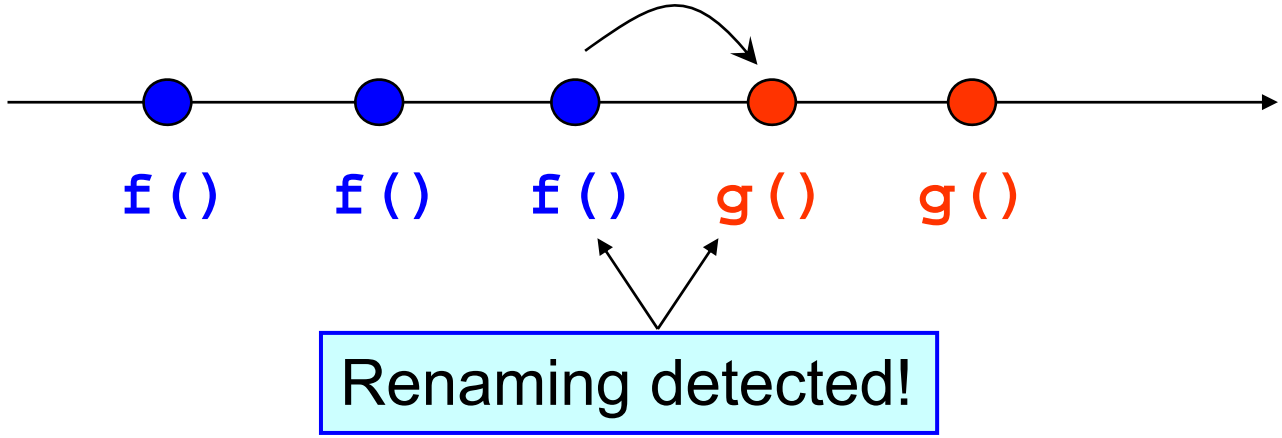
Entity traceability

By name:



By structure:

(1) Traceability by name fails
(2) There is no entity g() in previous release
(3) StructSim(f, g) ≥ T (=1)



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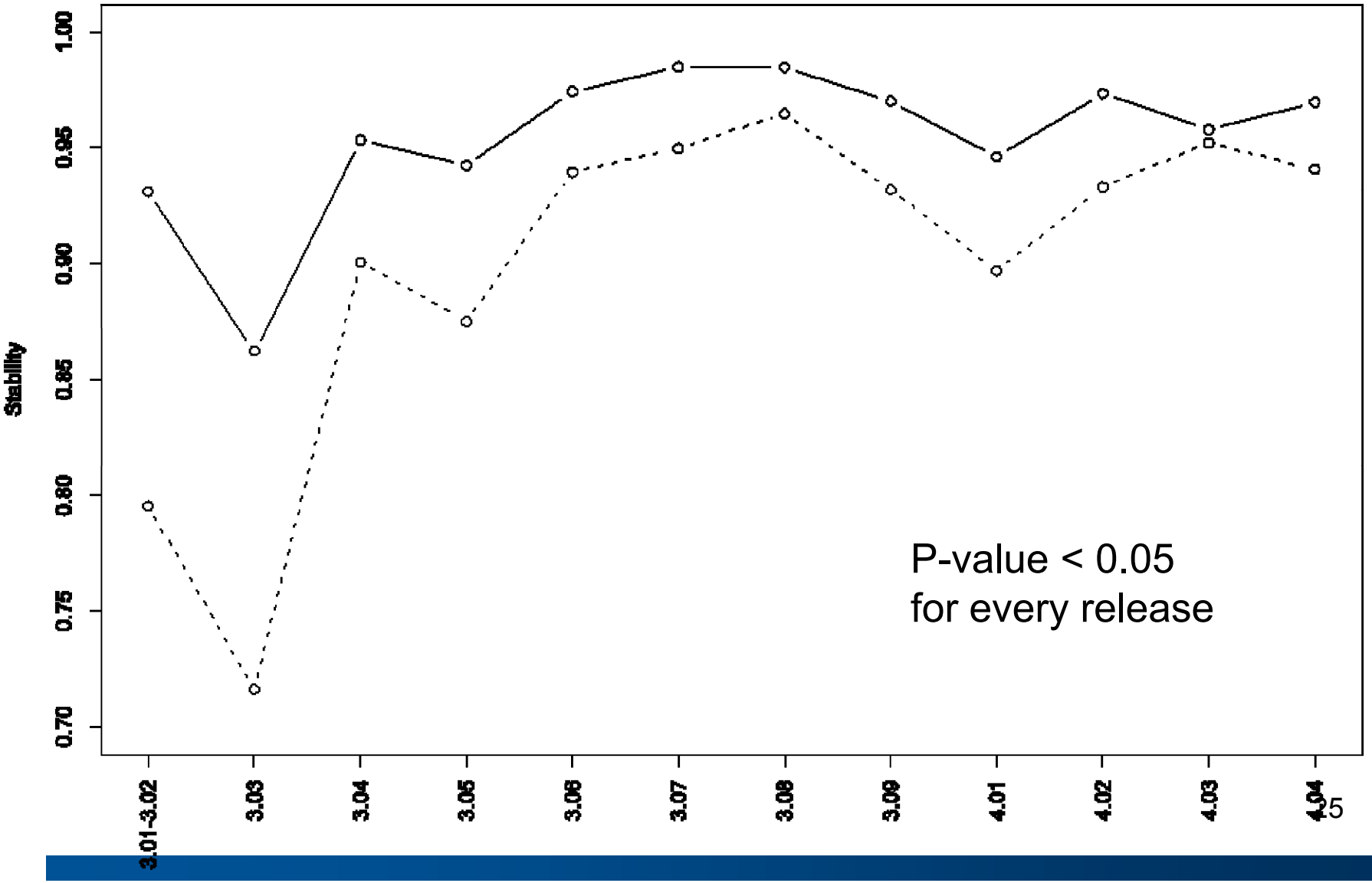
Subject systems

System	Language	Size	Versions	Identifiers
Eclipse	Java	2.9 MLOC	19	124187
Mozilla	C++	4.4 MLOC	24	55244
CERN/Alice	C++	0.825 MLOC	13	9002

Stability plot: Alice



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Renaming

Eclipse (Java):	AvgRenFreq = 7 / 106760 = 0.000065
Mozilla (C++):	AvgRenFreq = 0 / 51981 = 0
Alice (C++):	AvgRenFreq = 0 / 6736 = 0

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Results

RQ1 *(struct vs. lexicon evolution):*

- *Lexical and structural changes have different distributions over time; they probably obey different rules.*
- *Lexicon is always more stable than structure.*
- *Both structural and lexical stabilities tend to increase over time and tend to have correlated instabilities.*

RQ2 (*frequency of renamings*):

- *Renamings are rare during the evolution of a software system.*

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Discussion (our interpretations)

- A different change process holds for lexicon and structure.
- Programmers are generally reluctant to change the lexicon. Some possible reasons:
  - Optimistically, there is no need to do it (domain perfectly modeled by lexicon).
  - High cognitive burden associated with this kind of change.
  - No dedicated tool available.
- The development environment seems to have an influence on the evolution of the lexicon. A renaming tool available in the IDE may help (Java vs. C++ in our study).
  - Other tools that may help: glossaries, cross-referencing tools, abbreviation expansion tools, documentation tools (possibly using ontologies).

Corollary: A program written with a bad lexicon (`foo`, `bar`, `pippo`, `pluto` and the like) tends to keep its poor identifiers forever. Programmers must adapt to them; the inverse rarely happens.

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Empirical Study #2

RQ1: *How does the size of the source code vocabulary evolve over time?*

RQ2: *What are the relationships between individual vocabularies that form the source code vocabulary?*

RQ3: *Are new identifiers introducing new terms?*

RQ4: *What do the most frequent terms refer to?*

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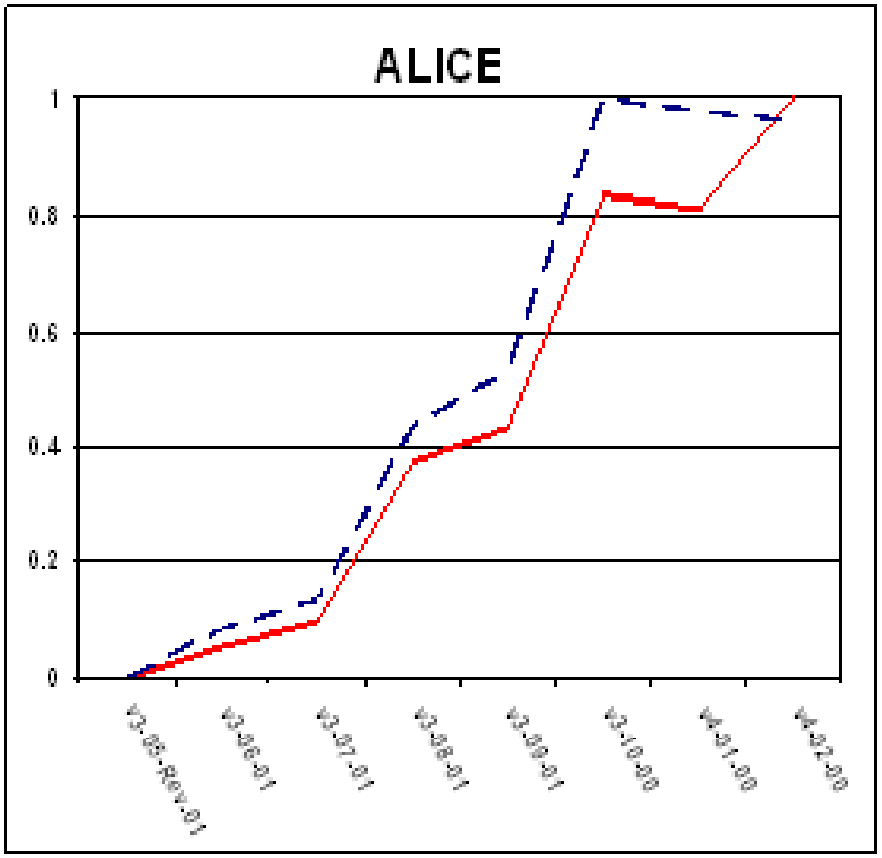
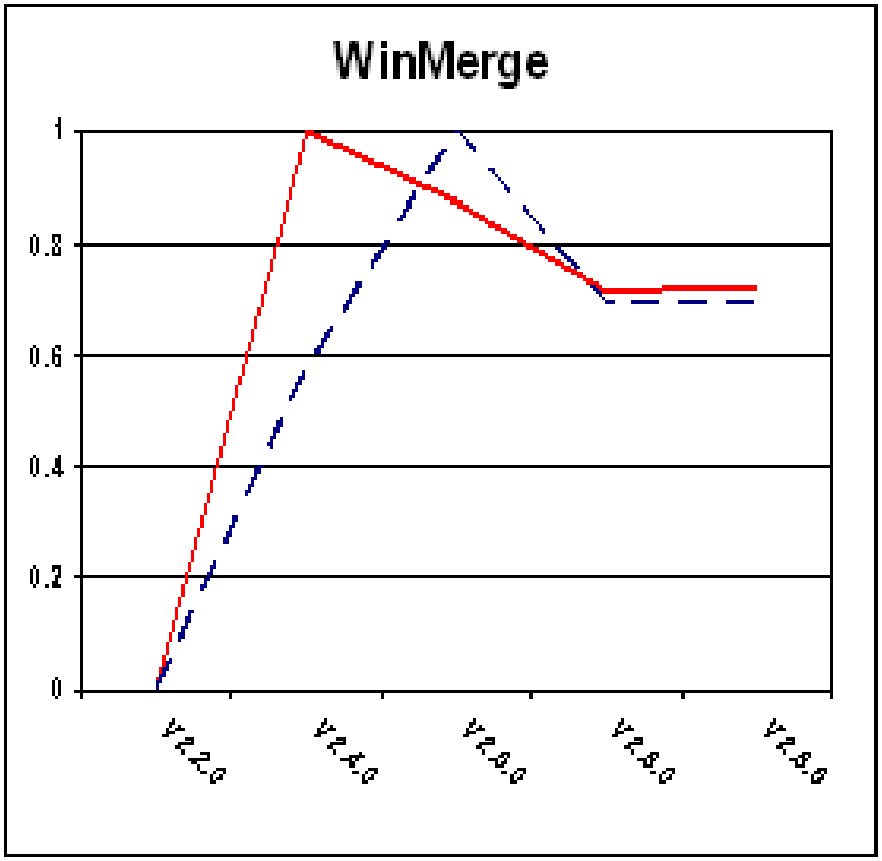
Vocabulary size





Vocabulary size (dashed) vs. code size (solid).

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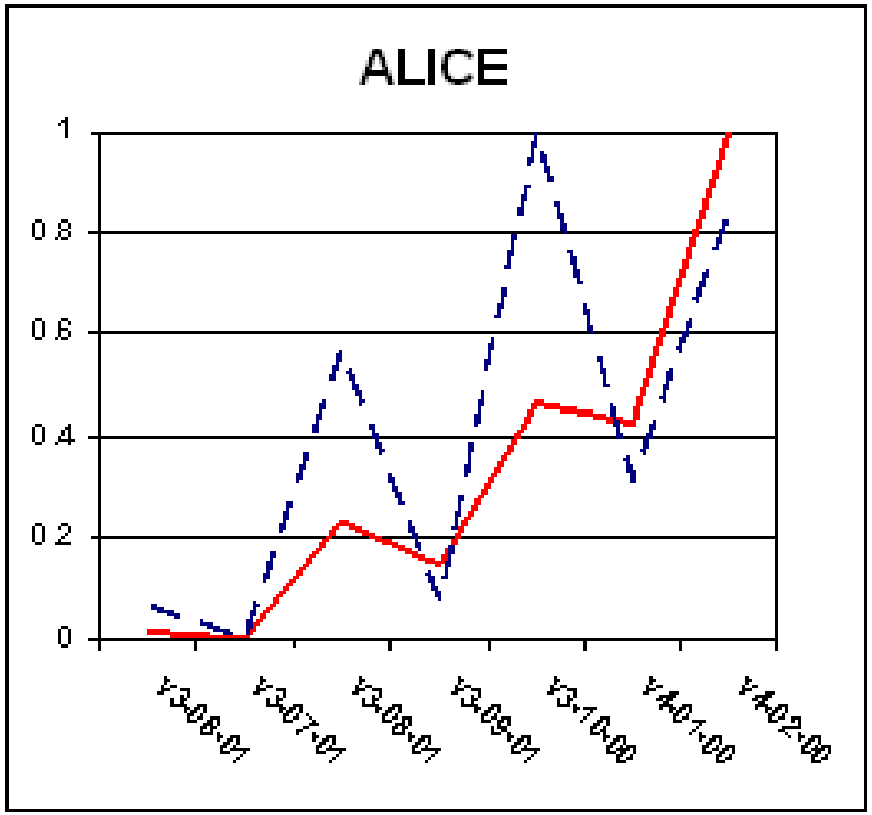
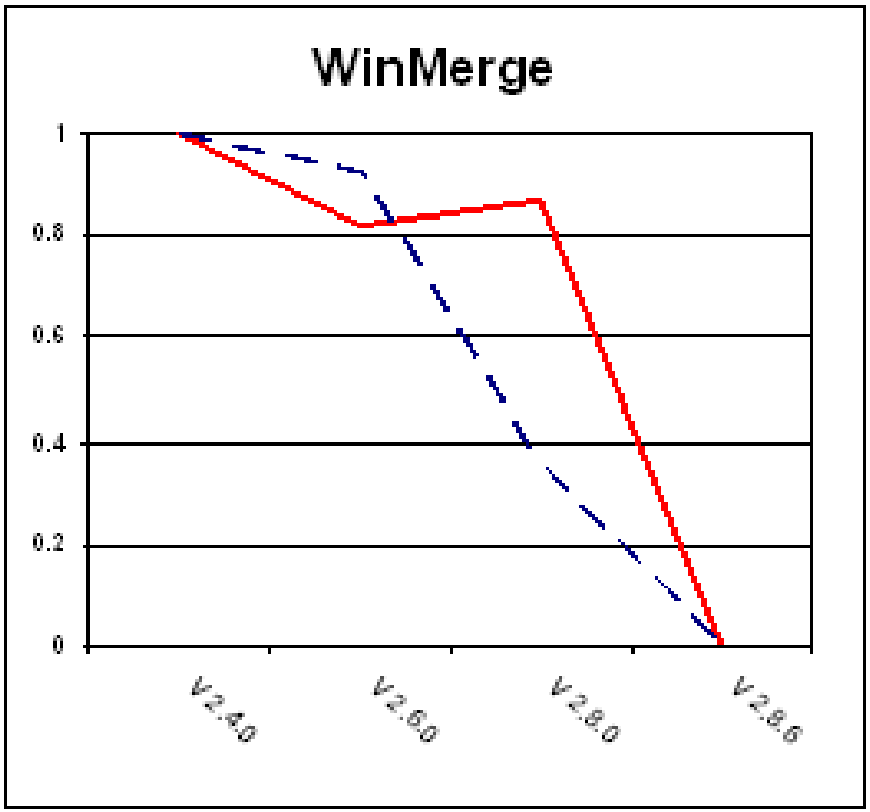
New terms





New terms (dashed) vs. new lines of code (solid).

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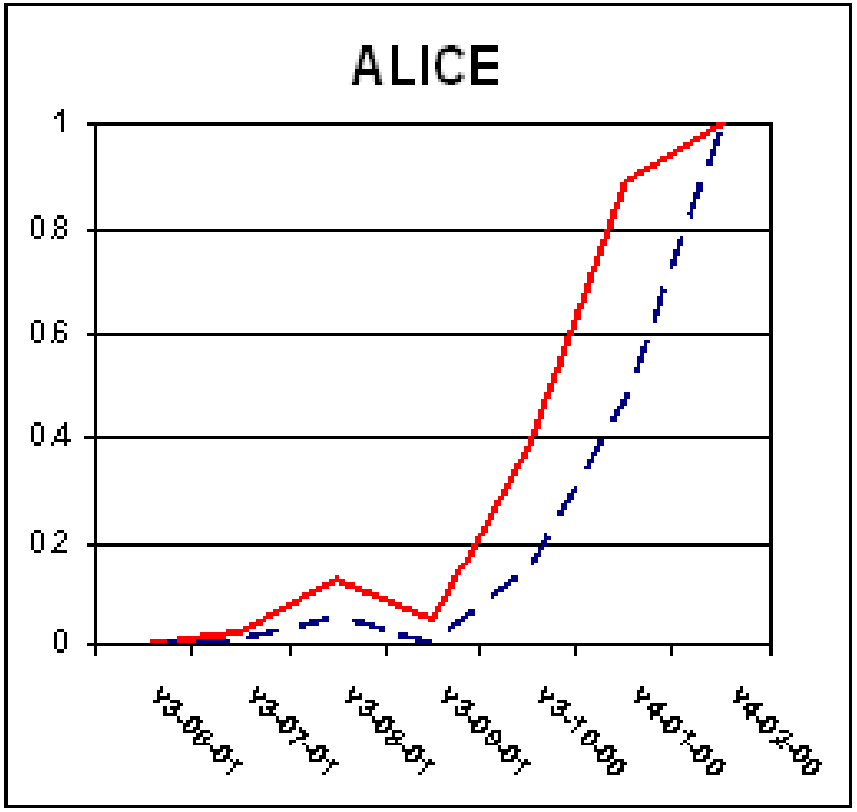
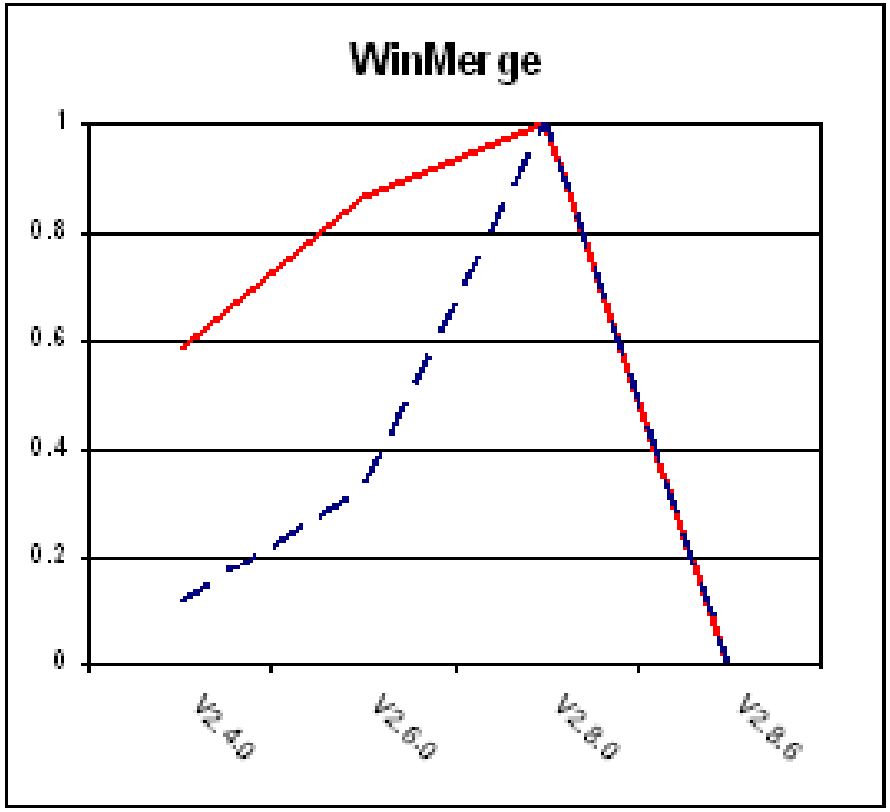
Deleted terms





Deleted terms (dashed) vs. deleted lines of code (solid).

Commonalities across vocabularies

		ALICE	WinMerge			ALICE	WinMerge
CV∩AV	Size	126	147	**AV∩PV**	Size	510	371
	% from CV	59%	76%		% from AV	43%	60%
	% from AV	11%	24%		% from PV	48%	48%
CV∩FV	Size	211	191	**AV∩CoV**	Size	878	555
	% from CV	99.7%	98%		% from AV	75%	90%
	% from FV	16%	17%		% from CoV	13%	10%
CV∩PV	Size	112	124	**FV∩PV**	Size	492	443
	% from CV	53%	64%		% from FV	38%	58%
	% from PV	10%	16%		% from PV	46%	40%
CV∩CoV	Size	203	194	**FV∩CoV**	Size	1,076	955
	% from CV	96%	100%		% from FV	83%	85%
	% from CoV	3%	3%		% from CoV	15%	17%
AV∩FV	Size	749	466	**PV∩CoV**	Size	757	627
	% from AV	64%	75%		% from PV	71%	82%
	% from FV	58%	42%		% from CoV	11%	11%

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New identifier terms appearing in comments

	ALICE	WinMerge
New CV∩CoV	30%	10%
New FV∩CoV	19%	16%
New AV∩CoV	15%	5%
New PV∩CoV	20%	14%

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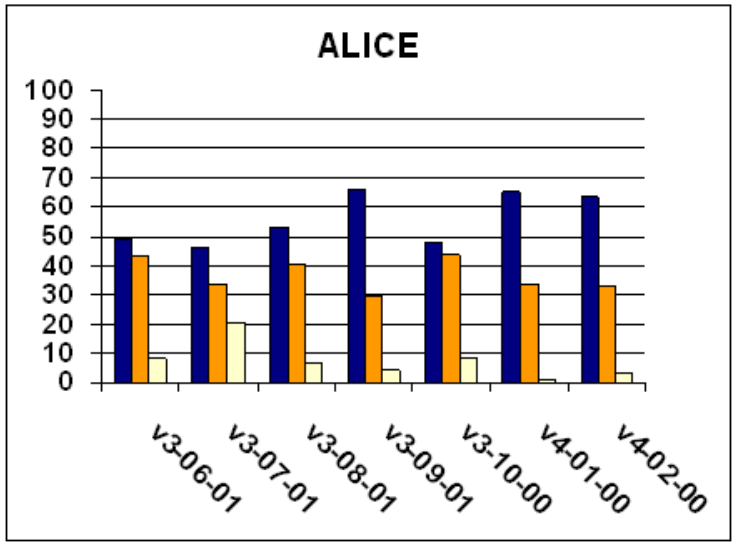
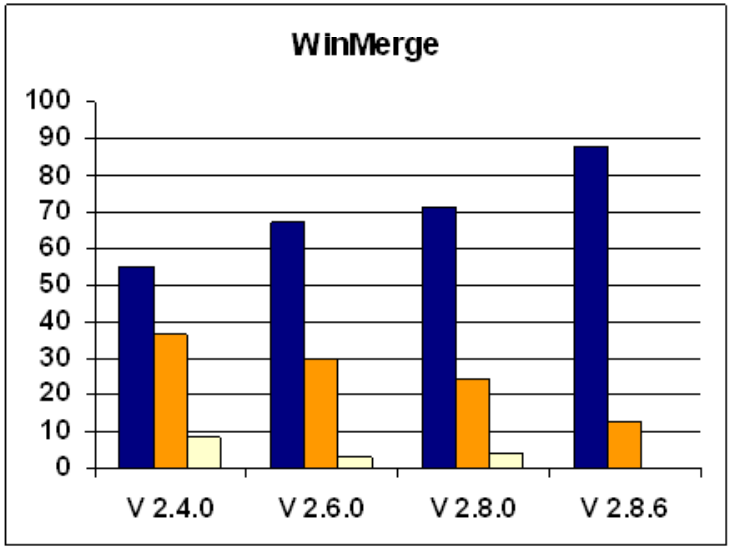
New identifiers



The % of new identifiers containing 0 new identifier terms

The % of new identifiers containing 1 new identifier terms

The % of new identifiers containing 2 or more new identifier terms



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Most frequent terms

***ALICE**:*
hit, track, pad, digit, cluster, chamber, pho, muon, segment, rec, event, tr, rich, tpc, trigger, tof, mp, tp, phosrp, cpv, emc, ppsd, energy, ev, sector, rh.

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Results

RQ1: System vocabulary and system size often exhibit a parallel evolution trend.

RQ2: The vocabulary used to build class identifiers has the largest number of terms in common with other vocabularies; identifier vocabulary changes are only marginally reflected in the comment vocabulary.

RQ3: New identifiers usually introduce no or at most one new term.

RQ4: Frequent terms are associated with core domain concepts.

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Discussion

- The vocabulary used by programmers is subject to an evolution pressure similar to that affecting code evolution.
- Keeping vocabulary evolution under control is a major challenge
- The quality of the vocabulary affects
  - how identifiers are constructed,
  - how core concepts are recognized and named, and
  - how difficult it is for a programmer to understand and evolve the system

From our study, we can envision a central role of class vocabulary terms and of frequent terms in recovering and structuring the knowledge conveyed by identifiers.

Improvement of the internal code quality

- Deal with natural language used in the code.
- Extract information about the natural language in the code and its evolution over time.
- Support natural language embedding and improvement by means of dedicated tools.

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Research agenda

- Domain modeling through ontology and relationship between domain terms and identifiers used in programs.
- Tools for identifier construction and improvement, based on domain models: support to concise and consistent naming [Deissenboeck & Pizka, IWPC 2005]
- Tools for code understanding, searching and browsing: dictionary/glossary of terms used in a program; concept based search and code navigation.