/* iComment:
Bugs or Bad Comments? */

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Motivation

• Software bugs affect reliability.
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  • Many due to mismatches between code and programmers’ assumptions.
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Assumption: Caller of reset_hardware acquires the lock.

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static int reset_hardware(...) {
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static int reset_hardware(...) {
    //access shared data.
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- Many due to mismatches between code and programmers’ assumptions.

Assumption: Caller of `reset_hardware` acquires the lock.

```c
static int reset_hardware(...) {
    //access shared data.
    ...

    ...

static int in2000_bus_reset(...) {
    ...
        reset_hardware(...);
    ...
}
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- Many due to mismatches between code and programmers’ assumptions.

Assumption: Caller of reset_hardware acquires the lock.

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linux/drivers/scsi/in2000.c:
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    //access shared data.
    ...
}
...
static int in2000_bus_reset(...) {
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    ...
}
```

No lock acquisition => A bug!
Prevalence of Comments

- Program comments express assumptions.
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- Millions lines of comments exist in software.

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• Comments are not fully utilized yet.
  • Ignored by compilers and bug detection tools.
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- Many assumptions are difficult to infer from source code alone.
  - Inferring from source code alone may fail
    - for cases that no (or only a few) places of the code follow the assumption.
- Use comment-code **redundancy** to detect comment-code mismatches.
Possibility (1): Bugs

- Mismatches indicate:
  - Possibility (1): Bugs
    - Due to time-constraints or other reasons.
    - Old code is not updated according to a new assumption.
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A bug automatically detected by iComment:

```c
linux/drivers/ata/libata-core.c:
/* LOCKING: caller. */
void ata_dev_select(...) {...}

...
int ata_dev_read_id(...) {
  ...
  ata_dev_select(...);
  ...
}
```
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Assumption in Comment.
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No lock is held before calling ata_dev_select.
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Assumption in Comment.

Mismatch!
The bug is already confirmed by Linux developers after we reported it.

No lock is held before calling ata_dev_select.
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A bad comment automatically detected by iComment:

```c
mozilla/security/nss/lib/ssl/sslsnce.c:
/* Caller must hold cache lock when calling this. */
static sslSessionID * ConvertToSID(...) {...}
...
static sslSessionID *ServerSessionIDLookup(...)
{   ...
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```

Assumption in Comment.

Cache lock is released before calling `ConvertToSID()`. 
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Assumption in Comment. Cache lock is released before calling ConvertToSID().

Mismatch! The bad comment is already confirmed by Mozilla developers after we reported it.
Possibility (2): Bad Comments

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- Our paper contains bad comment examples that already caused new bugs.
Challenges

- Goal: Detect comment-code inconsistencies.
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• Challenges of understanding comments written in natural language

• Various ways to paraphrase natural language
  • /* We need to acquire the write IRQ lock before calling ep_unlink(). */
  • /* Lock must be acquired on entry to this function. */
  • /* Caller must hold instance lock! */
Challenges

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• Various ways to paraphrase natural language
  • /* We need to acquire the write IRQ lock before calling ep_unlink(). */
  • /* Lock must be acquired on entry to this function. */
  • /* Caller must hold instance lock! */

• Use Natural Language Processing (NLP) techniques?
NLP alone is not enough.

- NLP only analyzes sentence structures.

1. POS Tagging (acc: 97%)
2. Chunking (acc: 90%)
3. Semantic Role Labeling (acc: 70%)
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  Caller  must  hold  instance  lock

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\[
\begin{array}{cccc}
\text{Caller} & \text{must} & \text{hold} & \text{instance} & \text{lock} \\
\text{Noun} & \cdots & \text{Verb} & \cdots & \text{Noun}
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Subject & & Verb & & Object \\
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- NLP is far from “understanding” natural language text.
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  Caller  must  hold  instance  lock

  \[ Subject \quad \text{Verb} \quad \text{Object} \]

  \[ Noun \quad \text{Verb} \quad Noun \]

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• NLP is **far from “understanding”** natural language text.

• Many comments are not even grammatically correct.

• Almost **impossible** to automatically analyze any arbitrary comments.
Idea & Contributions

• Took the first step to automatically analyze comments written in natural language to check for mismatches

• Combine Natural Language Processing (NLP), Machine Learning, Statistics, and Program Analysis

• Automatically extracted 1832 rules and detected 60 new bugs and bad comments (19 confirmed by developers)

• 2 topics, lock-related and call-related.

• Latest versions of 4 large software projects, Linux, Mozilla, Apache and Wine.
Outline

- Motivation, Challenges & Contributions
- Our Approach
  - Analyze comments written in natural language
  - Detect comment-code inconsistencies
- Methodology & Results
- Related work
- Conclusions
What to Analyze?

- What information is useful to extract?
- What information can be checked against code?
What is useful to extract?

- Two types of comments (examples from Linux):
  - Explain code segment: /* Set the clock rate */
  - Express assumptions/rules: /* Caller must hold instance lock! */

- We focus on rule-containing comments.
  - Likely to be inconsistent with code.
  - Likely to mislead programmers to introduce bugs.
What can be checked?

- Not everything in comments can be checked.
- Checking can only be done topic by topic.
  - Race detectors - race bugs
  - Purify, Valgrind, etc - memory bugs
- So our comment analysis is topic by topic.
  - A general framework allowing users to choose the topic, such as lock and call-from.
# Rule Template Examples

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| 1  | `<Lock L>` must be held before entering `<Function F>`.

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*lock related*
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- L, F, A and B are rule parameters.
- See our paper for many other templates supported.
- Many other templates can be added.
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- Statistics & NLP
- Topic keyword filtering - automatic
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Take lock as the topic:

```c
#A: /* return -EBUSY if a lock is held. */
#B: /* Lock must be held on entry to this function. */
#C: /* Caller must acquire instance lock! */
#D: /* Mutex locked flags */
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See our paper for details.

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Classifying Comments

- Machine Learning & NLP
- Automatically classify comments to different templates (give each comment a unique label)
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- Automatically classify comments to different templates (give each comment a unique label)

```c
#A: /* return -EBUSY if a lock is held. */
#B: /* Lock must be held on entry to this function. */
#C: /* Caller must acquire instance lock! */
... 
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#A: /* return -EBUSY if a lock is held. */
#B: /* Lock must be held on entry to this function. */
#C: /* Caller must acquire instance lock! */
...
```

No lock-related rule

Template 1

Template 1
Classifying Comments

- Machine Learning & NLP
- Automatically classify comments to different templates (give each comment a unique label)
- Core technique: Use learning classifier automatically built from a small set of manually labeled comments

```c
#A: /* return -EBUSY if a lock is held. */
#B: /* Lock must be held on entry to this function. */
#C: /* Caller must acquire instance lock! */
...```

- Template 1: No lock-related rule
- Template 1: Template 1
Decision Tree

Training Data:
- /* If no lock is held, zap it. */ - NO rule
- /* Called with the device lock held. */ - Template 1
- ...

Decision Tree Building Algorithm

Automatically generated Decision Tree
To be classified:

# A: /* return -EBUSY if a lock is held. */

# B: /* Lock must be held on entry to this function. */

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Training Data:

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  • ...

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**To be classified:**

- **# A:** /* return -EBUSY if a lock is held. */
- **# B:** /* Lock must be held on entry to this function. */
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Automatically generated Decision Tree

- **#A** → **0** No lock-related rule
- **#B** → **1** Template 1
- **#C** → **1** Template 1
Decision Tree

Feature selection is important.

To be classified:

# A: /* return -EBUSY if a lock is held. */
# B: /* Lock must be held on entry to this function. */
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Automatically generated Decision Tree

- #A: No lock-related rule
- #B: Template 1
- #C: Template 1
General-purpose Training

• The training is **optional for the users**
  • Done by us before releasing iComment (only once per topic).
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• Feasible because:
  • Programmers share wording and phrasing (confirmed by our correlated word results)
  • Cross-software training results show **decision trees trained on one software can classify comments from other software with high accuracy (~89%)**
General-purpose Training

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• Feasible because:
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• Took only about 2 hours to manually classify comments of 2 topics for Linux, Mozilla, Apache and Wine
Generating Rules

- NLP & Program Analysis
- What are the parameters?
Generating Rules

- NLP & Program Analysis
- What are the parameters?
  - The function name is right after the comment.
Generating Rules

• NLP & Program Analysis

• What are the parameters?
  • The function name is right after the comment.
  • The lock name is the object of the verb.

/* Caller must hold instance lock! */
Generating Rules

- NLP & Program Analysis

- What are the parameters?
  - The function name is right after the comment.
  - The lock name is the object of the verb.

- Is the rule positive or negative?
  - Positive if the verb is not modified by a negation word.
Rule Checker

- Use static analysis for checking
  - Flow-sensitive, and context sensitive
  - Simple point-to analysis

- Mismatch report ranking
  - Support
  - Violation
Outline

• Motivation, challenges & contributions

• Our Approach
  • Analyze comments written in natural language
  • Detect comment-code inconsistencies

• Methodology and Results

• Related work

• Conclusions
Methodology

- Latest versions of 4 large software projects
- 2 topics: lock-related and call-related
- 18% of comments are used for training on average.
  - Our training sensitivity analysis provides guidance on how much training data to use (find detailed results in our paper).

<table>
<thead>
<tr>
<th>Software</th>
<th>LOC</th>
<th>LOM</th>
<th>Language</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linux</td>
<td>5.0M</td>
<td>1.0M</td>
<td>C</td>
<td>OS</td>
</tr>
<tr>
<td>Mozilla</td>
<td>3.3M</td>
<td>0.51M</td>
<td>C&amp;C++</td>
<td>Browser Suite</td>
</tr>
<tr>
<td>Wine</td>
<td>1.5M</td>
<td>0.22M</td>
<td>C</td>
<td>Program to Run WinApp on Unix</td>
</tr>
<tr>
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<td>0.057M</td>
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# Overall Results

<table>
<thead>
<tr>
<th>Software</th>
<th>Mismatches</th>
<th>Bugs</th>
<th>BadCom</th>
<th>FP</th>
<th>Rules</th>
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<tr>
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- **Automatically detected 60 new bugs and bad comments**
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- **19 new bugs and bad comments already confirmed** by the corresponding developers.
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- Automatically detected **60 new bugs and bad comments**
  - **19** new bugs and bad comments already **confirmed** by the corresponding developers.

- Major causes of false positives
  - Mostly caused by inaccuracy from checking
  - Incorrectly generated rules
Training Accuracy

- **Accuracy** = the percentage of correctly labeled comments
- **Software-specific** training accuracy (lock-related)

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<td>Accuracy</td>
<td>90.8%</td>
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Other measures, such as Kappa and Macro-F score, show similar results. Accuracies for call-related comments are similar.
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Accuracies for call-related comments are similar.

- **Cross-software** training accuracy (lock-related)

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<td>Linux</td>
<td>81.5%</td>
<td>78.6%</td>
<td>83.3%</td>
</tr>
<tr>
<td>Linux + Mozilla</td>
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<td>89.3%</td>
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- Training can be done by us before releasing iComment to analyze users’ software.
Related Work

- **Extracting rules from source code and execution behaviors** [SOSP01 & OSDI06 Engler et. al., Daikon, ...]:
  - Our approach complements these techniques.

- **Annotation Language** [Microsoft SAL, Java annotations, Splint, SafeDrive, Sparse, ...]:
  - Not as expressive: usability
  - Not widely adopted vs. millions lines of comments already exist.

- **Automatic document generation from comments** [C# XML comments, JavaDoc, Doxygen, RDoc, ...]:
  - Do NOT analyze the natural language part
  - Share similar challenges of analyzing unstructured comments.
Conclusions

- Comment-code inconsistencies hurt software quality and reliability.
- **First work** to automatically analyze comments written in natural language for mismatch detection
  - iComment automatically extracted **1832 rules** on 2 topics and detected **60 new bugs and bad comments** (19 confirmed by developers)
- **More work in this direction!**
  - Analyze other system documents in natural language
Acknowledgments

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Gopal Krishna
Yuanyuan (YY) Zhou

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University of Illinois
at Urbana-Champaign