Mining Software Repositories for Intelligent Software Maintenance

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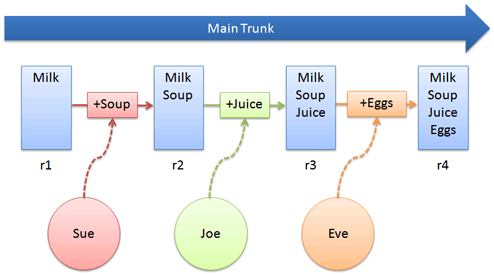
Executive Summary

- Change management with version control systems
- Improving software maintenance through software repository mining
- Framework for preventive maintenance
- Novelty: Metrics for localization
- Study of Open Source projects

Outline

Version Control



- Management of changes to computer files in a repository
- Changes identified by a number or letter code (“revision”)
- Each revision associated with timestamp and person making the change
- Version control systems: CVS, Subversion, Git, ...

Working Copy, Commits and Change Sets

- Working copy: Local copy of files from a repository
- Commit: Writing changes to the working copy into the repository
- Change set: Set of changes made in a single commit

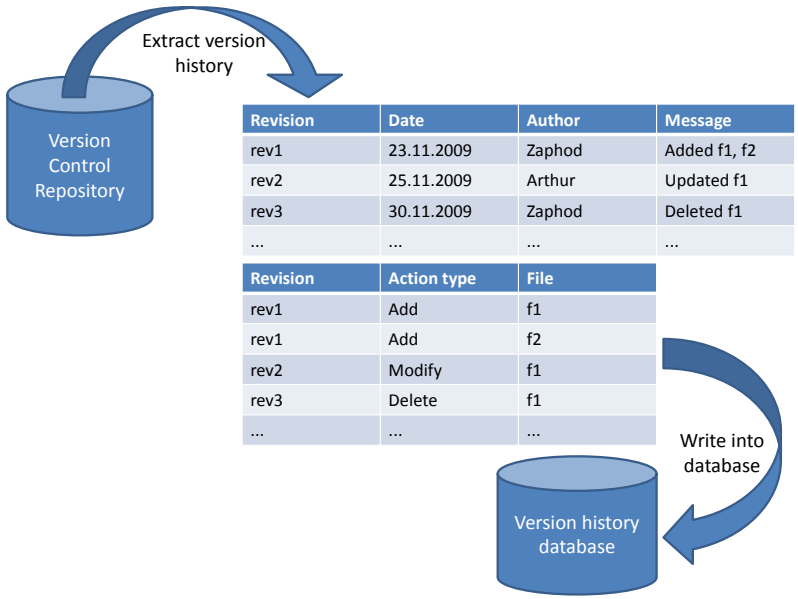
```
commit 3d2d827f5ca5e32816194119d5c980c7e04474a6
Author: Michael S. Tsirkin <mst@redhat.com>
Date:   Mon Sep 21 17:03:51 2009 -0700

    mm: move use_mm/unuse_mm from aio.c to mm/

M       fs/aio.c
A       include/linux/mmu_context.h
M       mm/Makefile
A       mm/mmu_context.c
```


Outline

Software Repository Mining

- Version control systems contain large amounts of historical information: "*Who* changed *what*, *why* and *when*."
- Learn from the past to shape the future
- Automated extraction, collection, and abstraction of information from software development data

Populating Version History Database



Frequent Item Set Mining

- Popular method for market basket analysis
- Identify sets of products frequently bought together: Beer and diapers
- Framework applies frequent item set mining to the version history of software repositories
- Identify which code files have been frequently changed together

Source: http://research.nii.ac.jp/~uno

Frequent Item Set Mining: Transactions

- Transactions: Change sets
- Example:

```
{ fs/aio.c, include/linux/mmu_context.h,
  mm/Makefile, mm/mmu_context.c }
```

```
commit 3d2d827f5ca5e32816194119d5c980c7e04474a6

M       fs/aio.c
A       include/linux/mmu_context.h
M       mm/Makefile
A       mm/mmu_context.c
```


Frequent Item Set Mining: Definitions

- Transaction database contains all change sets
- Members of transactions are items
- Item set is a subset of possible items
- Support of an item set i: $\sup(i) :=$ number of transactions t that contain i

Frequent Item Set Mining: Association Rules

Source: amazon.com

- If a customer buys bread and wine, then she will probably also buy cheese
- Problem decomposed into two subproblems:
  - Finding frequent item sets with minimum support
  - Generate association rules with minimal confidence
- Confidence for association rule $R : X \rightarrow Y$: $\text{conf}(R) = \text{conf}(X \rightarrow Y) = \sup(X \cup Y)/\sup(X)$

Frequent Item Set Mining: Example

Transaction IDs	Transactions (Files)
1	$\{1, 2, 3, 4\}$
2	$\{2, 3, 4\}$
3	$\{2, 3\}$
4	$\{1, 2, 4\}$
5	$\{1, 2, 3, 4\}$
6	$\{2, 4\}$

Maintenance Challenges

- Predicting changes
  - Incomplete changes
- Traceability links
  - "Cross-language" changes
- Predicting faults
- Understanding software evolution
  - Measure change localization

Predicting Changes

A. Ying, G. Murphy et al., *Predicting Source Code Changes by Mining Change History*

- Determines change patterns from change history of the code base
- Uses association rule mining for identifying implicit dependencies
- Change patterns can be used to recommend potentially relevant source code to a developer performing a modification task

Predicting Changes: Incomplete Change

- Comments in modification task report of Mozilla:
  - 2002-06-12 14:14: Patch to gtk/nsFontMetricsGTK.cpp, limiting the size of fonts to twice the display height.
  - 2002-06-12 14:37: Patch misses the Xlib version.
  - A patch was later submitted with the correct changes in the X-windows font handling code in the file xlib/nsFontMetricsXlib.cpp
- gtk/nsFontMetricsGTK.cpp does not reference xlib/nsFontMetricsXlib.cpp $\rightarrow$ used in different configurations
- Files were changed 41 times together $\rightarrow$ change pattern
- Changing the gtk/nsFontMetricsGTK.cpp could trigger a recommendation for xlib/nsFontMetricsXlib.cpp

Traceability Links

H. Kadgi et al., *Mining Software Repositories for Traceability Link*

- If files of difference types are co-changed with a high frequency over multiple versions → potential traceability link
- Traceability links derived from the actual changes to files by mining software repositories
- Uses sequential-pattern mining to identify and analyze sets of files that are committed together
- Sequential-pattern mining produces ordered lists of co-changing files
- Ordering information can be used to infer directionality

Traceability Links: Example

- Mining change sets in the Wine repository
- Changes are tested:
  - `./dlls/gdiplus/graphicspath.c -> ./dlls/gdiplus/tests/graphicspath.c`
  - `./dlls/inetmib1/main.c -> ./dlls/inetmib1/tests/main.c`
- Cross language changes:
  - `./dlls/rpcrt4/tests/server.c -> ./dlls/rpcrt4/tests/server.idl`
  - `./dlls/dxgi/dxgi_private.h -> ./include/wine/winedxgi.idl`

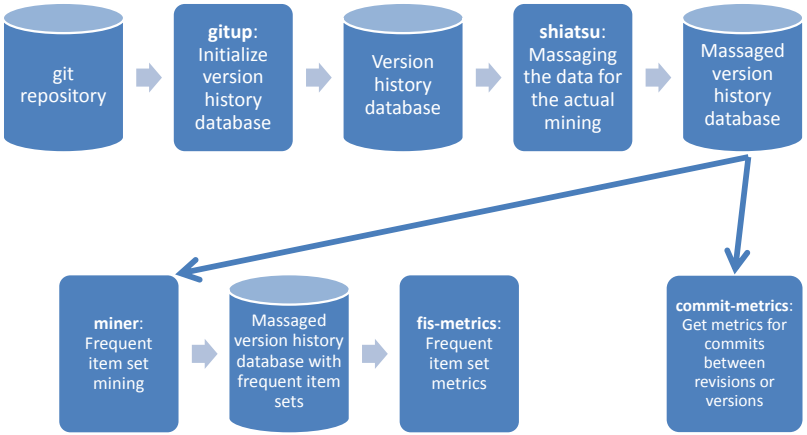
Predicting Faults

S. Kim, T. Zimmermann et al., *Predicting Faults from Cached History*

- Assumption: faults do not occur in isolation, but rather in bursts of several related faults
- Identifying bug fixes by mining commit messages: Searching for keywords such as “Fixed” or “Bug” and references to bug reports like “42”
- Cache locations that are likely to have faults
- By consulting the cache at the moment a fault is fixed, a developer can detect likely fault-prone locations

Outline

Architecture



Git

- Free distributed version control system
- Initially designed and developed for Linux kernel development
- Every working directory is a full-fledged repository:
  - Complete history
  - Full revision tracking capabilities
  - Not dependent on network access or a central server
- Easily convert repositories of other version control systems like Subversion into Git repositories
- Only need to write mining and analysis tools for one format rather than many

Populating the Version History Database

- Gitup generates logfile and initializes versions history database
- Shiatsu massages the data to be used by the metrics applications
  - Set modularization according to specified directory depth
  - Remove deleted files
  - Set number of modifications
  - Heuristics for file moves
- Massaged version history database is used to generate frequent item sets and calculate metrics

Preventing Maintenance

Our framework can help with solving all mentioned maintenance challenges:

- Predicting changes
  - Incomplete changes
- Traceability links
  - "Cross-language" changes
- Predicting faults
- Understanding software evolution
  - Measure change localization

Outline

Change Localization

- A change is well localized, if it touches only one or very few modules
- A change is not well localized, if it touches many modules
- Apply change localization for frequent item sets

Hypothesis

Changes in frequent item sets in well modularized software systems are localized

Change Localization: Example

- Well localized: Touches only one module

```
dlls/ntdll/signal_i386.c
dlls/ntdll/thread.c
```

- Badly localized: Touches four modules out of five possible

```
if1632/thunk.c
include/process.h
loader/task.c
scheduler/process.c
scheduler/thread.c
```

- Not localized at all: Touches all possible modules

```
files/dos_fs.c
scheduler/syslevel.c
tools/winapi-check
```


Change Localization Metrics

- Value between 0 and 1
- 0: Not localized at all
- 1: Fully localized

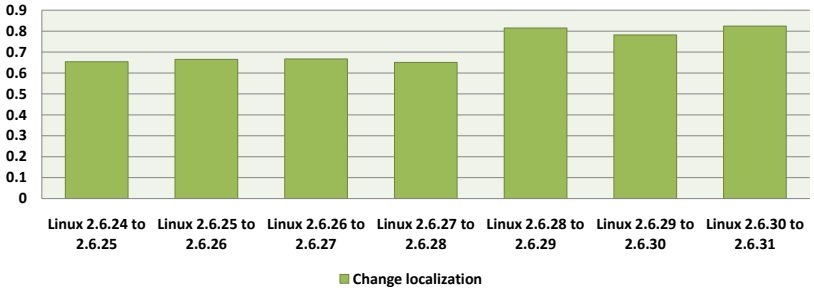
$$\frac{\sum_{i=\mathrm{FIS}_1}^{\mathrm{FIS}_n} 1 - \left(\mathrm{if}\left(i.\mathrm{modules\_touched} = 1, 0, \frac{i.\mathrm{modules\_touched}}{i.\mathrm{files\_touched}}\right)\right)}{n}$$

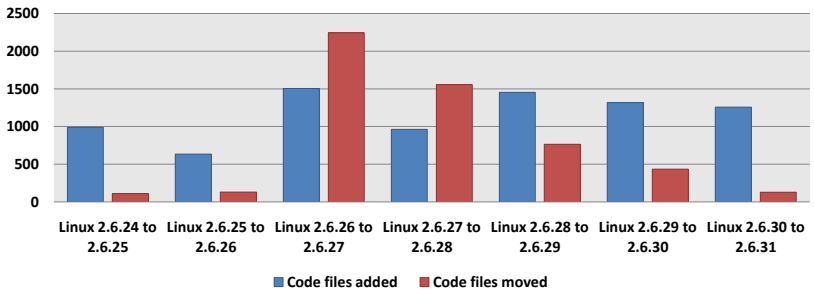
Outline

Linux 2.6

- Unix-like operating system kernel
- Repository checked out on November 19, 2009
- 25,277 code files
- 168,800 commits
- Frequent item set mining:
  - Minimum number of commits (modifications) for code files: 4
  - Minimum support: 4
  - Maximum size of commits (number of code files): 50

Linux 2.6: Frequent Item Set Metrics

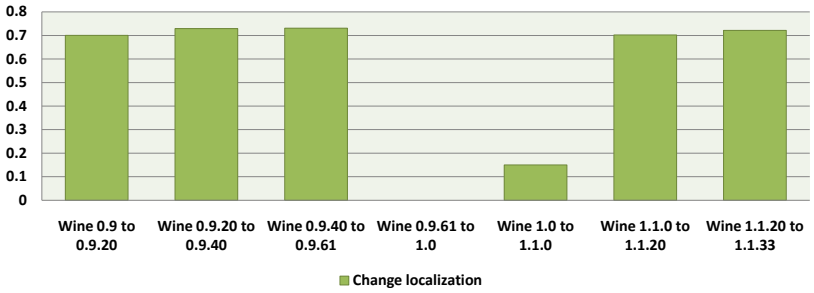


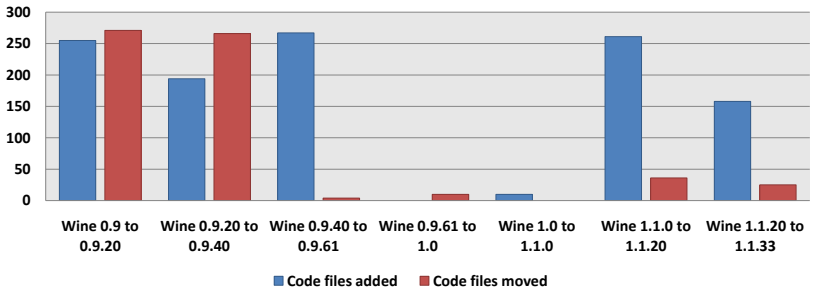


Wine

- Allows execution of Microsoft Windows programs on Unix-like operating systems
- Repository checked out on November 20, 2009
- 3,479 code files
- 63,864 commits
- Frequent item set mining:
  - Minimum number of commits (modifications) for code files: 4
  - Minimum support: 4
  - Maximum size of commits (number of code files): 50

Wine: Frequent Item Set Metrics





Insights

- Code file moves increase localization
- Adding of many code files decrease localization
- Adding of code files can clear effect of moves on localization
- Stable versions contain mostly bug fixes
  $\Rightarrow$ low localization, only few moves and adds
- Unstable versions contain mostly new features
  $\Rightarrow$ high localization, many moves and adds

Future Work

- Use framework to mine software repositories of commercial systems
- Compare localization metrics of Open Source and Closed Source systems
- Use the frequent item sets extracted to come up with a better modularization
- Publish research in the form of a paper

Summary

- Mining software repositories for intelligent software maintenance
- Applications of frequent item set mining in improving software maintainability
- Framework for preventing software maintenance
- New metrics for change localization
- Localization of frequent item sets of Open Source projects