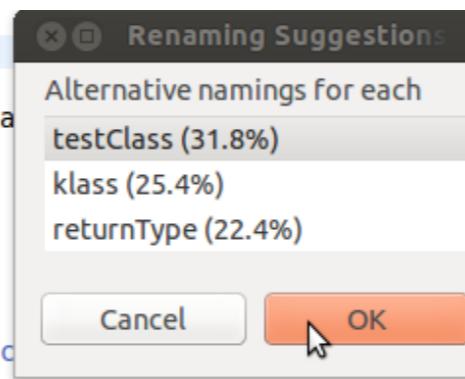


```
private Test testCaseForClass(Class<?> each) {  
    if (TestCase.class.isAssignableFrom(each)) {  
        return new TestSuite(each.asSubclass(TestCase.class));  
    } else {  
        return warning(each.getCanonicalName() + " is not a test case");  
    }  
}  
  
/**  
 * Constructs a TestSuite from the given array of classes.  
 */  
public static TestSuite suiteForClasses(Class[] classes) {  
    TestSuite suite = new TestSuite("All Tests");  
    for (Class each : classes) {  
        suite.addTest(testCaseForClass(each));  
    }  
    return suite;  
}
```



```
for (Iterator iter=$methodInvoke;  
     iter.hasNext(); )  
{$BODY$}
```

Statistical Analysis of Computer Program Text

Charles Sutton
University of Edinburgh
& The Alan Turing Institute

Companion Site: <http://bit.ly/sutton-nlpswe>



THE UNIVERSITY of EDINBURGH
informatics

The
Alan Turing
Institute

Microsoft®
Research

EPSRC
Engineering and Physical Sciences
Research Council

Source code is a means of human communication



public static final
String \$name = \$StringLit;

try{
 Node \$name=\$methodInvoke();
 \$BODY\$
}finally{
 \$(Transaction).finish();
}

Over **20 billion** lines of open source code online

Implicit knowledge about how to write code

- Uses common libraries
- Avoids common bugs
- Easy to read and maintain

Source code as a means of human communication

Perhaps PL text has NL-style regularities

Statistical NLP techniques for identifying patterns in PL text

Every NLP problem has SWE analogue

- | | |
|--|---|
| <ul style="list-style-type: none">★ Spelling correction★ Finding co-locations<ul style="list-style-type: none">• Summarisation• Generation★ Machine Translation<ul style="list-style-type: none">• Question Answering | <ul style="list-style-type: none">★ Semantic Parsing<ul style="list-style-type: none">• Semantic Entailment• Information Extraction★ Information Retrieval<ul style="list-style-type: none">• Grounding Semantics★ Statistical Parsing (!) |
|--|---|

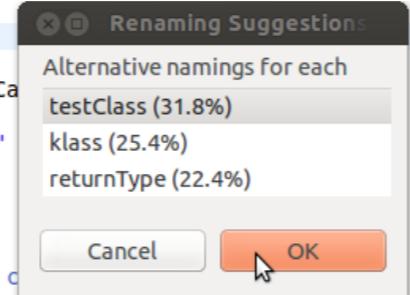
Every SWE activity can benefit from NLP+ML

- Defining requirements
- Architecting
- ★ Implement systems
- Reading
- ★ Navigation
- ★ Maintenance
 - Optimising performance
 - Validation
- ★ Refactoring
- ★ Porting

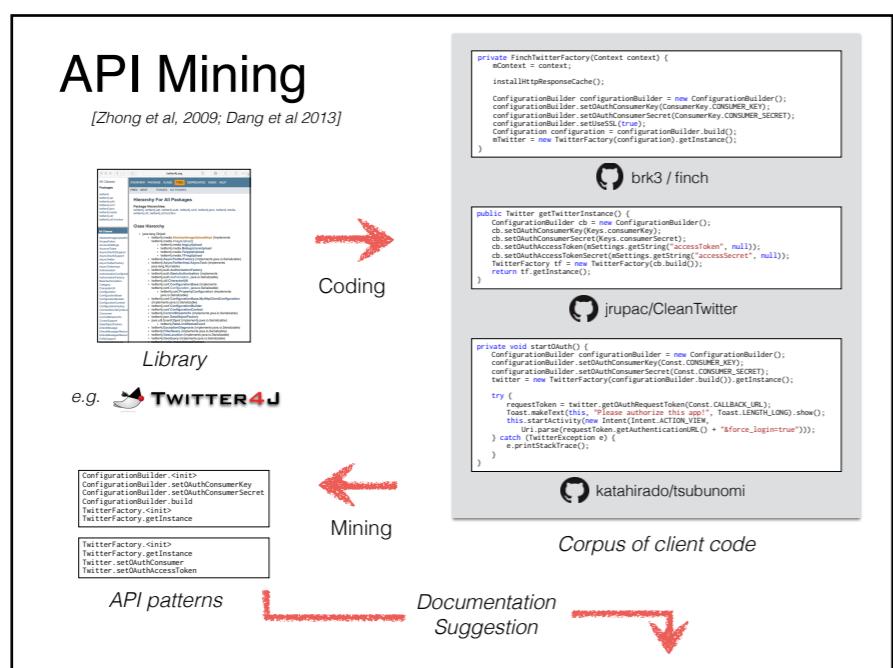


```
private Test testCaseForClass(Class<?> each) {
    if (TestCase.class.isAssignableFrom(each)) {
        return new TestSuite(each.asSubclass(TestCase.class));
    } else {
        return warning(each.getCanonicalName() + " is not a test case");
    }
}

/**
 * Constructs a TestSuite from the given array of classes.
 */
public static TestSuite suite(Class<?>... classes) {
    TestSuite suite = new TestSuite();
    for (Class<?> each : classes) {
        suite.addTest(testCaseForClass(each));
    }
    return suite;
}
```



Learning coding conventions



(structure learning)

```
while (($(String) = $(BufferedReader).readLine()) != null) {
    $BODY$}
}
```

```
while (($(String) = $(BufferedReader).readLine()) != null) {
    $BODY$}
}
```

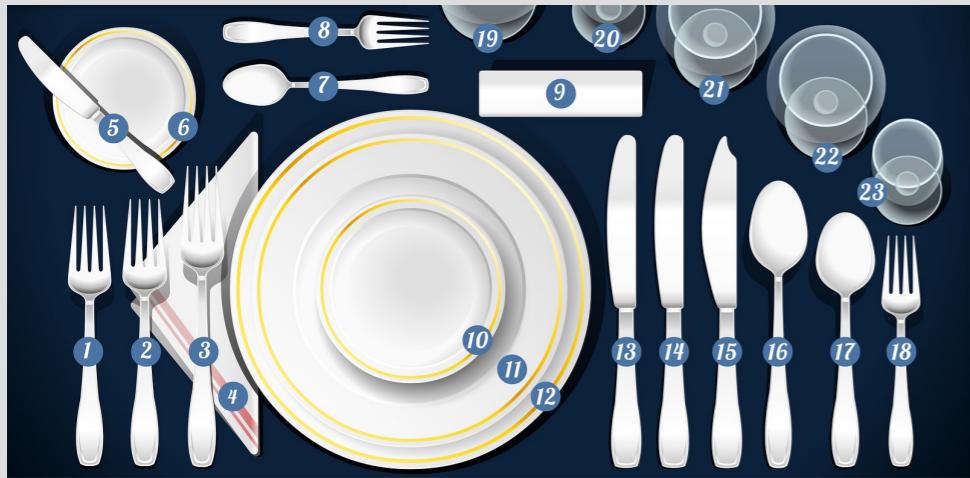


Mining idioms (probabilistic grammars)

```
1 /* Header */
2 package org.zoolu.sip.header;
3
4 /** SIP Status-line, i.e. the first
5  * line of a response message */
6 public class Statusline {
7     protected int code;
8     protected String reason;
9
10    /* Construct Statusline */
11    public Statusline(int c, String r) {
12        code = c;
13        reason = r;
14    }
15
16    /* Create a new copy of the request-line */
17    public Object clone() {
18        return new Statusline(getCode(), getReason());
19    }
20
21    /* Indicates whether some other Object
22     * is "equal to" this Statusline */
23    public boolean equals(Object obj){
24        if (obj instanceof Statusline) {
25            Statusline r = (Statusline) obj;
26            if (r.getCode() == getCode() &
27                r.getReason().equals(getReason()))
28                return true;
29            else
30                return false;
31        } catch (Exception e) {
32            return false;
33        }
34    }
35
36    public int getCode() {
37        return code;
38    }
39
40    public String getReason() {
41        return reason;
42    }
43
44    public String toString() {
45        return "SIP/2.0 " + code + " " + reason + "\r\n";
46    }
47}
```

```
1 /* Header */
2 package org.zoolu.sip.header;
3
4 /** SIP Status-line, i.e. the first...
5  * line of a response message */
6 public class Statusline {
7     protected int code;
8     protected String reason;
9
10    /* Construct Statusline */
11    public Statusline(int c, String r) {
12        code = c;
13        reason = r;
14    }
15
16    /* Create a new copy of the request-line */
17    public Object clone() {
18        return new Statusline(getCode(), getReason());
19    }
20
21    /* Indicates whether some other Object
22     * is "equal to" this Statusline */
23    public boolean equals(Object obj){
24        if (obj instanceof Statusline) {
25            Statusline r = (Statusline) obj;
26            if (r.getCode() == getCode() &
27                r.getReason().equals(getReason()))
28                return true;
29            else
30                return false;
31        } catch (Exception e) {
32            return false;
33        }
34    }
35
36    public int getCode() {
37        return code;
38    }
39
40    public String getReason() {
41        return reason;
42    }
43
44    public String toString() {
45        return "SIP/2.0 " + code + " " + reason + "\r\n";
46    }
47}
```

Code summarization (topic models)



Learning Natural Coding Conventions

A **coding convention** is a syntactic constraint beyond that imposed by the language grammar

Coding Conventions

Developers care

- Create style guides
- Enforce during code reviews



Research in SWE

- Boogerd and Moonen, 2008
- Caprile and Tonella, 2000
- Takang, 1996

gofmt

indent



Importance of Conventions

Code Review
Discussions

Conventions 38%

Naming 24%

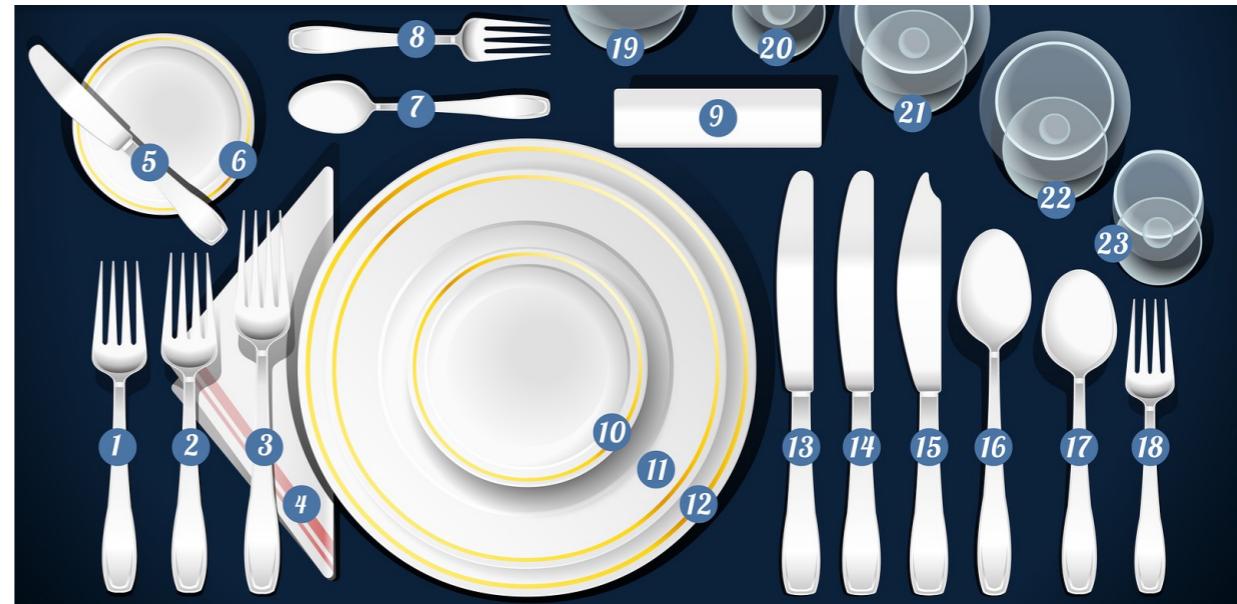
Formatting 9%

Study at Microsoft:

169 code reviews with 1,093 discussion threads.

Where conventions come from?

- Too many to agree explicitly
- Instead arise *implicitly*
- Soft constraints (mores) rather than hard constraints (laws)



New developers don't know about implicit conventions

Coding convention inference problem:

Learn conventions from examples of conventional code

junit/src/test/java/junit/tests/runner/TextRunnerTest.java

```
public class TextRunnerTest extends TestCase {  
    void execTest(String testClass, boolean success) throws Exception {  
        ...  
        InputStream i = p.getInputStream();  
        while ((i.read()) != -1);  
        ...  
    }  
    ...  
}
```

Score by ngram model
and threshold

input (81.93%)

Suggest
alternate
names

input
InputStream
is
stream

Learning Formatting Conventions

```
5     @Override public void  
6         write(int arg0) throws IOException {  
7     }  
8 }
```

```
5 INDENT1n3s @ SPACE0 ID SPACE1s public SPACE1s void  
6 INDENT1n0 ID SPACE0 ( SPACE0 ID SPACE1s ID SPACE0 ) SPACE1s  
7 throws SPACE1s ID SPACE1s {  
8 INDENT1n0 }  
8 INDENT1n-3s }
```

Evaluation Methodology

Automatic evaluation:

- Top 10 Java projects on GitHub
- Perturb existing code
- Measure: does Naturalize retrieve ground truth.

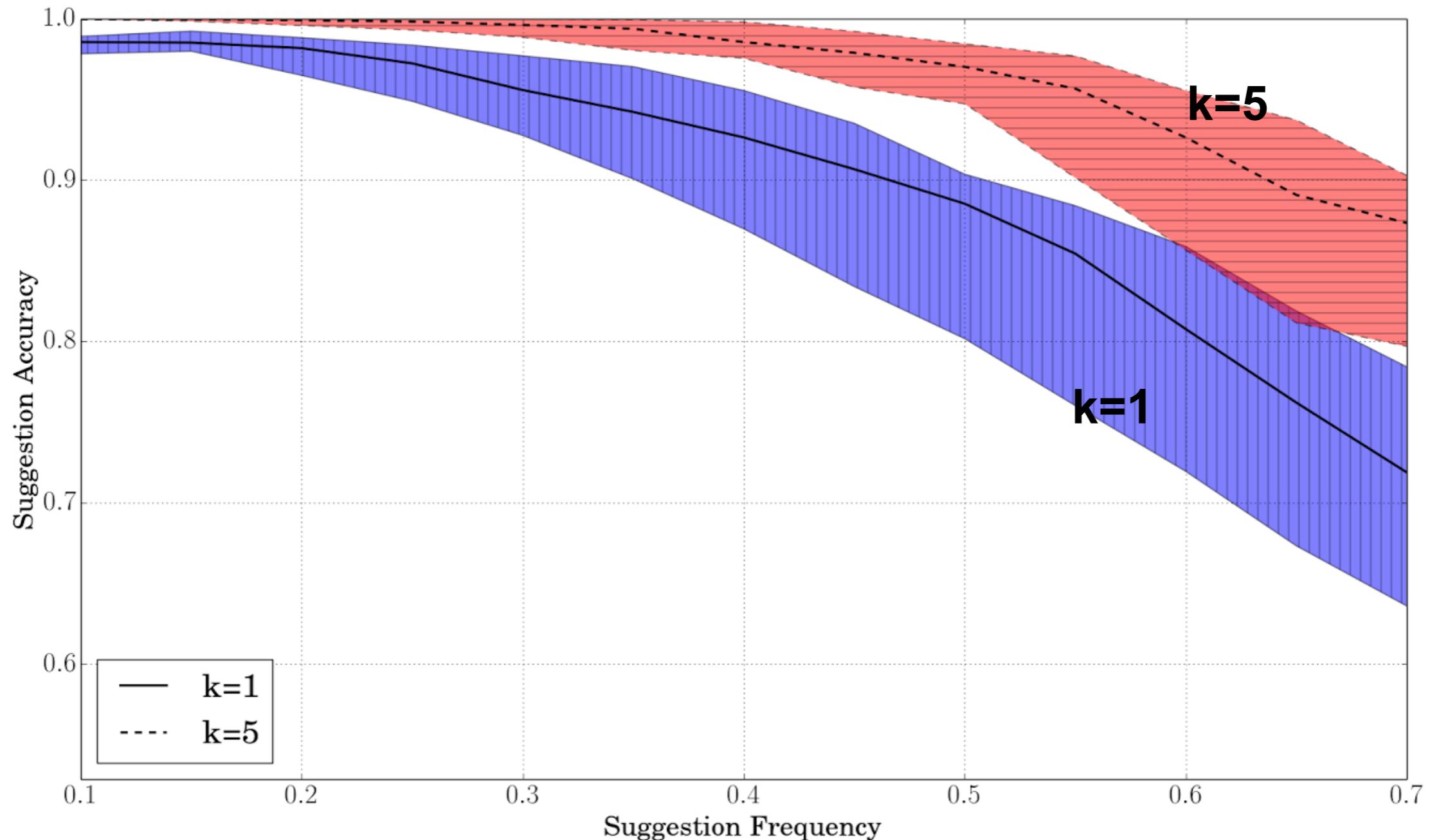
```
ForkJoinTask<?> XYZZY;
if (task instanceof ForkJoinTask<?>)
    XYZZY = (ForkJoinTask<?>) task;
else
    XYZZY = new ForkJoinTask.AdaptedRunnableAction(task);
externalPush(XYZZY);
```



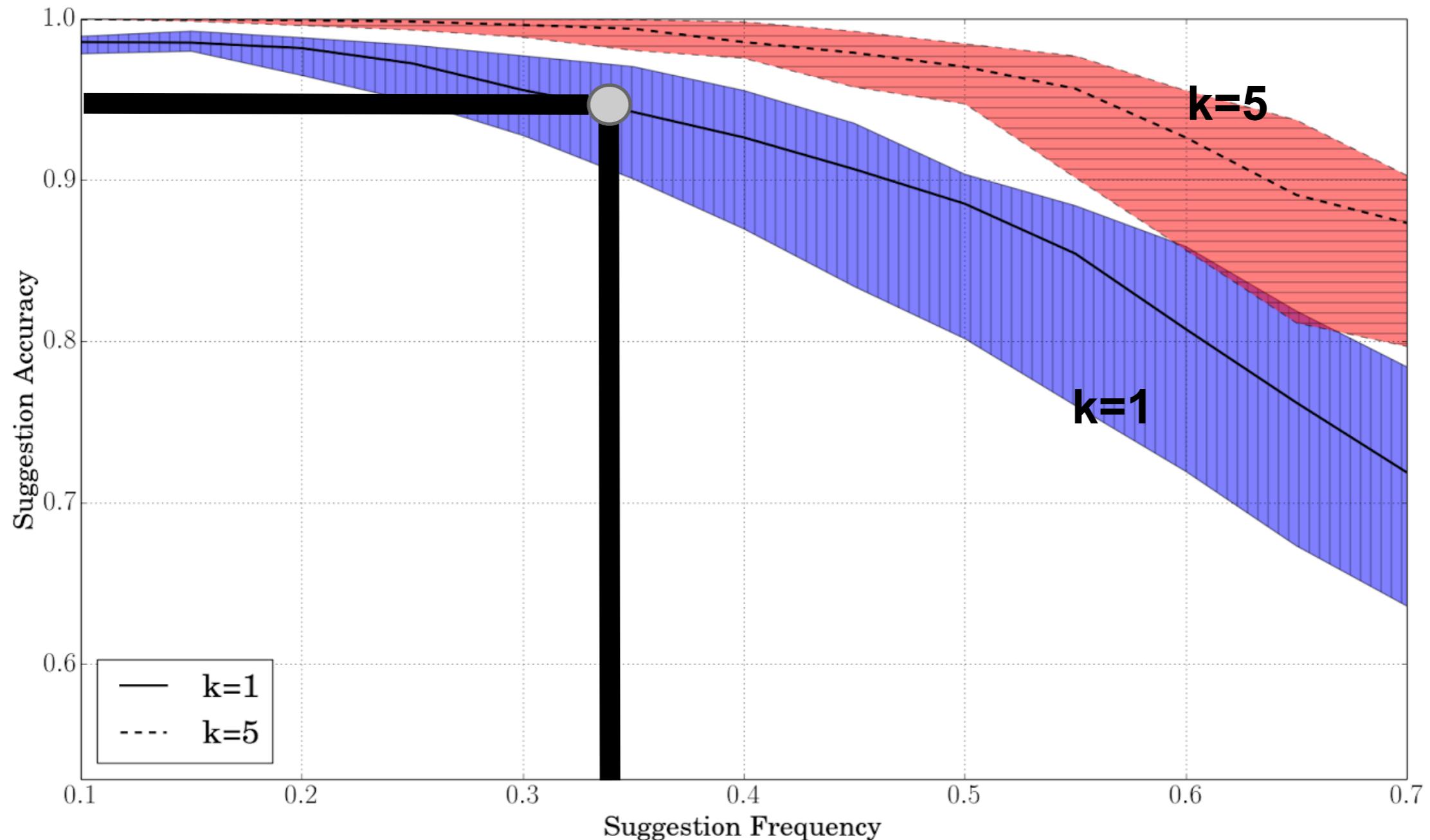
Naturalize

1. job (30%)
2. task (20%)
3. tsk (15%)

Variable Renaming



Variable Renaming

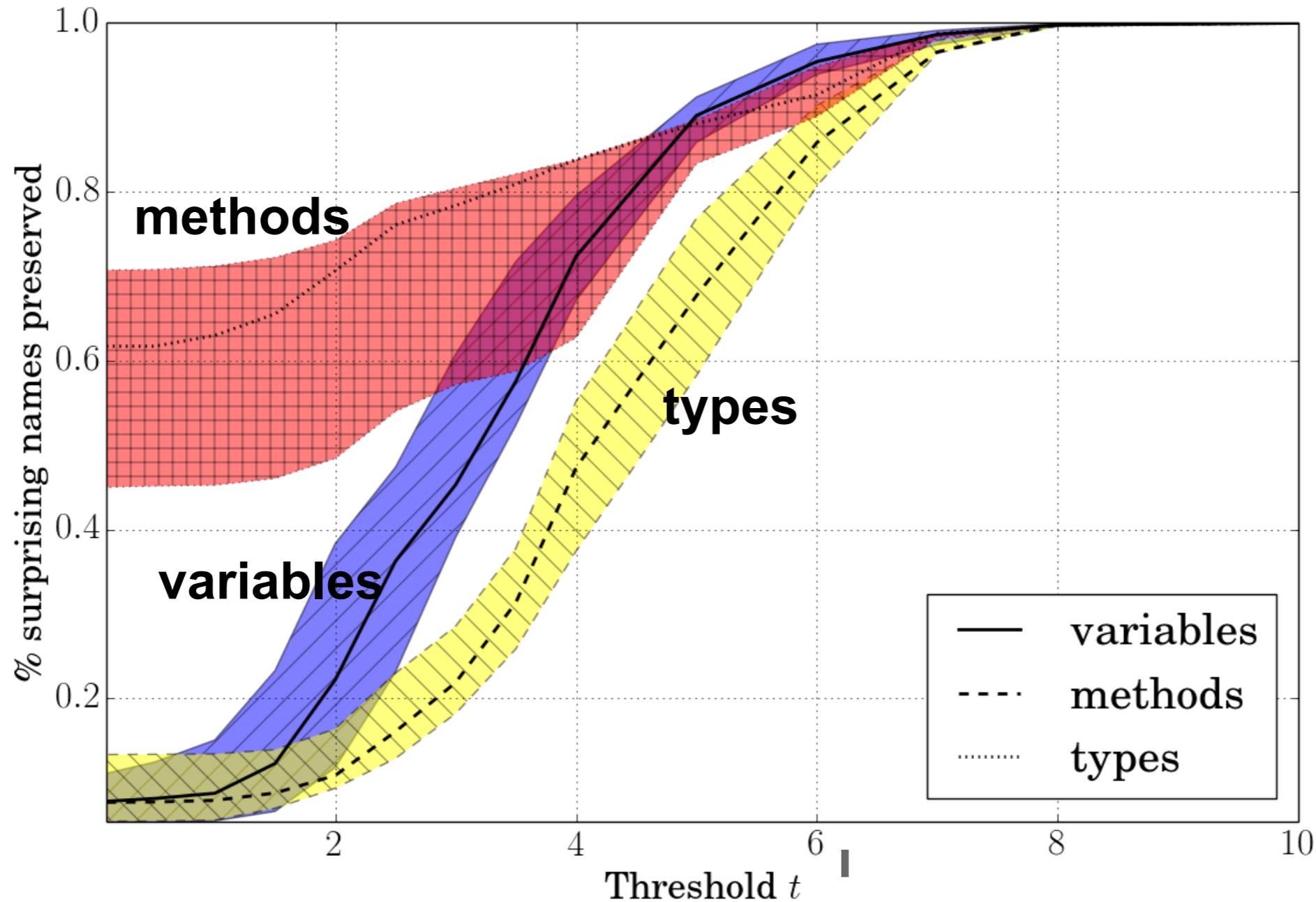


Sympathetic Uniqueness

Rare names often signify unusual functionality.
These should be preserved.

- Prune rare words
- Introduce special UNK token
- Naturalize suggests UNK → a rare name is expected. Don't suggest change.

Sympathetic Uniqueness



Rare names can be rare for good reason; do we persevere those?

GitHub

The screenshot shows a GitHub pull request interface. On the left, a vertical timeline of events is displayed:

- mallamanis** added some commits on 10 Feb:
 - Renamed the ImmutableBlobContainer container to blobContainer. ... af0f713
 - Renamed XContentParser.Token named "t" to "token". ... 7d092c2
 - Renamed ClusterBlocks variable named "block" to "blocks". ... 35301ce
- Javanna** added **enhancement** **v1.2.0** **v2.0.0** label
- Javanna** self-assigned this on 7 Apr
- Javanna** commented on 7 Apr:

Merged, thanks!
- Javanna** closed this on 7 Apr

On the right, the main commit history and discussions are shown:

- mallamanis** added some commits on 26 Feb:
 - Renamed "i" (15.46%) to "index" (31.34%). The naturalize tool detected ... b522d52
 - Renamed "value" (18.55%) to "scalar" (51.13%). The naturalize tool ... 46d4393
 - Minor changes in JavaDoc
 - Renamed "vector" (7.51%) to "point" (64.23%). The naturalize tool ... 5d6dffcc
 - Renamed "scale" (24.02%) to "scaleXY" (75.98%). The naturalize tool ... 33726e2
- sinistersnare** commented on 26 Feb:

Very interesting project, and thanks for the contribution!
I've always wanted to spend a good amount of time using findbugs with libgdx, there's a ton of recommendations it provides.
- badlogic** commented on 26 Feb:

Wow, that's a pretty cool tool!
- badlogic** closed this on 26 Feb
- badlogic** reopened this on 26 Feb
- badlogic** merged commit **3d5040f** into **libgdx:master** from **mallamanis:master** on 26 Feb **Revert**

**18 patches for 5 open source projects:
14 accepted - 4 still waiting**

Extensions / future work

- Neural network language models
[Allamanis, Barr, Bird and Sutton, 2015]
- Method and class naming
 - Convolutional attention mechanism
[Allamanis, Peng and Sutton, 2016]
- Future work
 - Longer distance context
 - Code semantics
 - LSTMs

Mining Idioms from Code

```
while (((String) = $(BufferedReader).  
        readLine()) != null) {  
    $BODY$  
}  
  
while (((String) = $(BufferedReader).  
        readLine()) != null) {  
    $BODY$  
}
```



A code idiom is a syntactic code fragment that recurs frequently across software projects and has a single semantic purpose.

What are Code Idioms? Example

Looping through lines of a BufferedReader

```
while (((String) = $(BufferedReader).  
        readLine()) != null) {  
    $BODY$  
}
```

Idioms Contain Gaps

Looping through lines of a BufferedReader

```
while (((String) = $(BufferedReader).  
        readLine()) != null) {
```

\$BODY\$

}

→ gap (non-terminal)

Idioms Contain Metavariables

Looping through lines of a BufferedReader

```
while (((String) = $(BufferedReader).
           readLine()) != null) {
    $BODY$
}
```



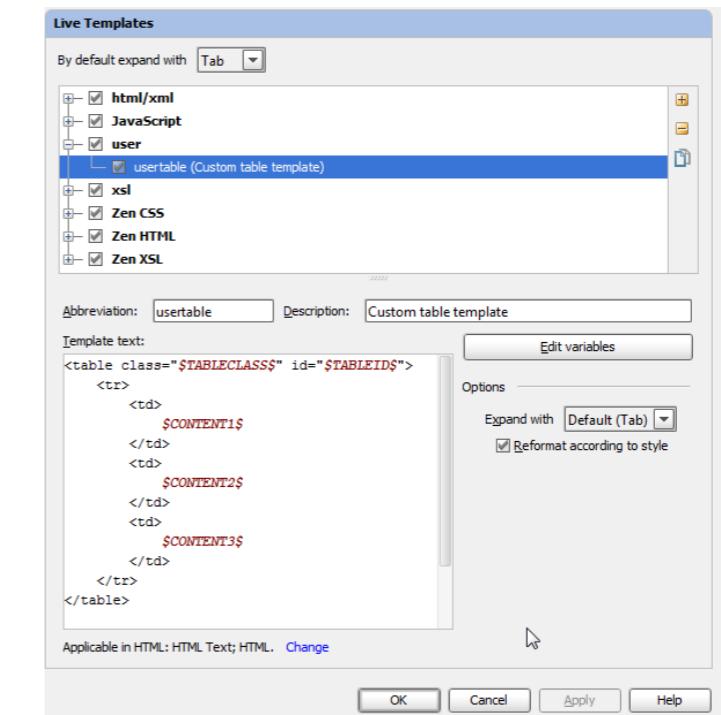
Metavariables

Idiom-Related Tools

A screenshot of Microsoft Visual Studio Code. The code editor shows a C# file with the following code:1 using System;
2
3 namespace Demo
4 {
5 class Program00
6 {
7 static void Method01(string[] args)
8 {
9 string pth = "c:\\file.txt";
10 //how to read file pth line by line
11 }
12 }
13 }A tooltip is displayed over the line `//how to read file pth line by line` containing several suggestions from the dotnetperls.com source:

- Console.WriteLine File string Main ReadLines Program
- Console.WriteLine ReadLine StreamReader finally Close
- Console.WriteLine StreamWriter finally Close Message
- Console.WriteLine ReadLine StreamReader readwriteapp finally Close
- Console.WriteLine StreamWriter readwriteapp finally Close
- Console.WriteLine ReadLine File string Main Program
- Console.WriteLine ReadLine File string while != App
- Console.WriteLine ReadLine StreamReader File final Close
- Console.WriteLine ReadLine StreamReader Close string
- sr var RemoveEmptyEntries StringSplitOptions ToChar

Microsoft Visual Studio Code Assistant



IntelliJ IDEA live templates

A screenshot of the Eclipse SnipMatch interface. A code editor window shows Java code with a cursor at the word 'tab'. A proposal list titled 'tab' is open, listing several Eclipse SWT components related to tables.

- TabFolder - new TabFolder - eclipse, swt, widge
- TabItem - new TabItem for a TabFolder - eclips
- Table - new Table - eclipse, swt, widget
- TableColumn - new TableColumn for a Table -
- TableItem - new TableItem for a Table - eclips

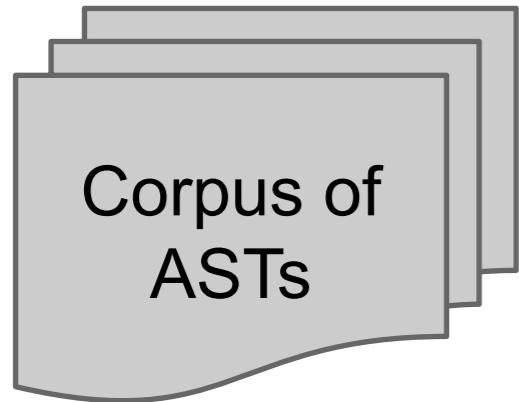
```
org.eclipse.swt.widgets.Table table = new org.eclipse.swt.widgets.Table(parent, SWT.SINGLE | SWT.FULL_SELECTION);
table.setLayoutData(new org.eclipse.swt.layout.GridLayout(3, true));
table.setLinesVisible(true);
table.setHeaderVisible(true);

for (int i = 0; i < table.getColumnCount(); i++) {
    table.getColumn(i).pack();
}
```

Press 'Tab' from proposal table or click for focus

Eclipse SnipMatch

The Idiom Mining Problem



Corpus of
ASTs



Idioms

```
try{
    Node $name=$methodInvoke();
    $BODY$
}finally{
    $(Transaction).finish();
}

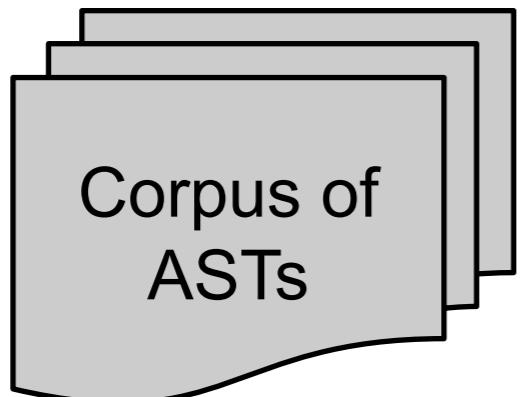
Location.distanceBetween(
    $(Location).getLatitude(),
    $(Location).getLongitude(),
    $...);

Document doc=Jsoup.connect(URL).
    userAgent("Mozilla").
    header("Accept","text/html").
    get();

while (((String) = $(BufferedReader).
    readLine()) != null) {
    $BODY$
```

The Idiom Mining Problem

HAGGIS



Idioms

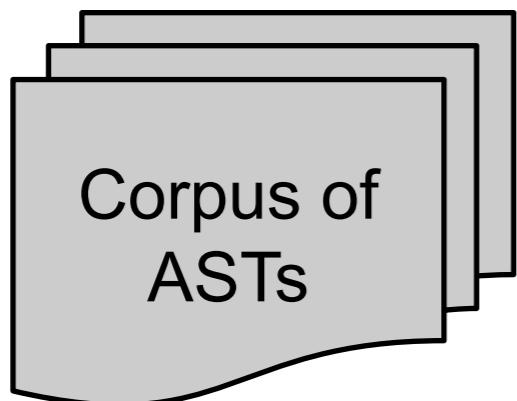
```
try{  
    Node $name=$methodInvoc();  
    $BODY$  
}finally{  
    $(Transaction).finish();  
}  
  
Document doc=Jsoup.connect(URL).  
    userAgent("Mozilla").  
    header("Accept","text/html").  
    get();  
  
Toast.makeText(this,  
    $stringLit,Toast.LENGTH_SHORT)  
.show()  
  
Location.distanceBetween(  
    $(Location).getLatitude(),  
    $(Location).getLongitude(),  
    $...);  
  
while (($(String) = $(BufferedReader).  
    readLine()) != null) {  
    $BODY$  
}
```



Holistic, Automatic Gathering of
Grammatical Idioms from Software

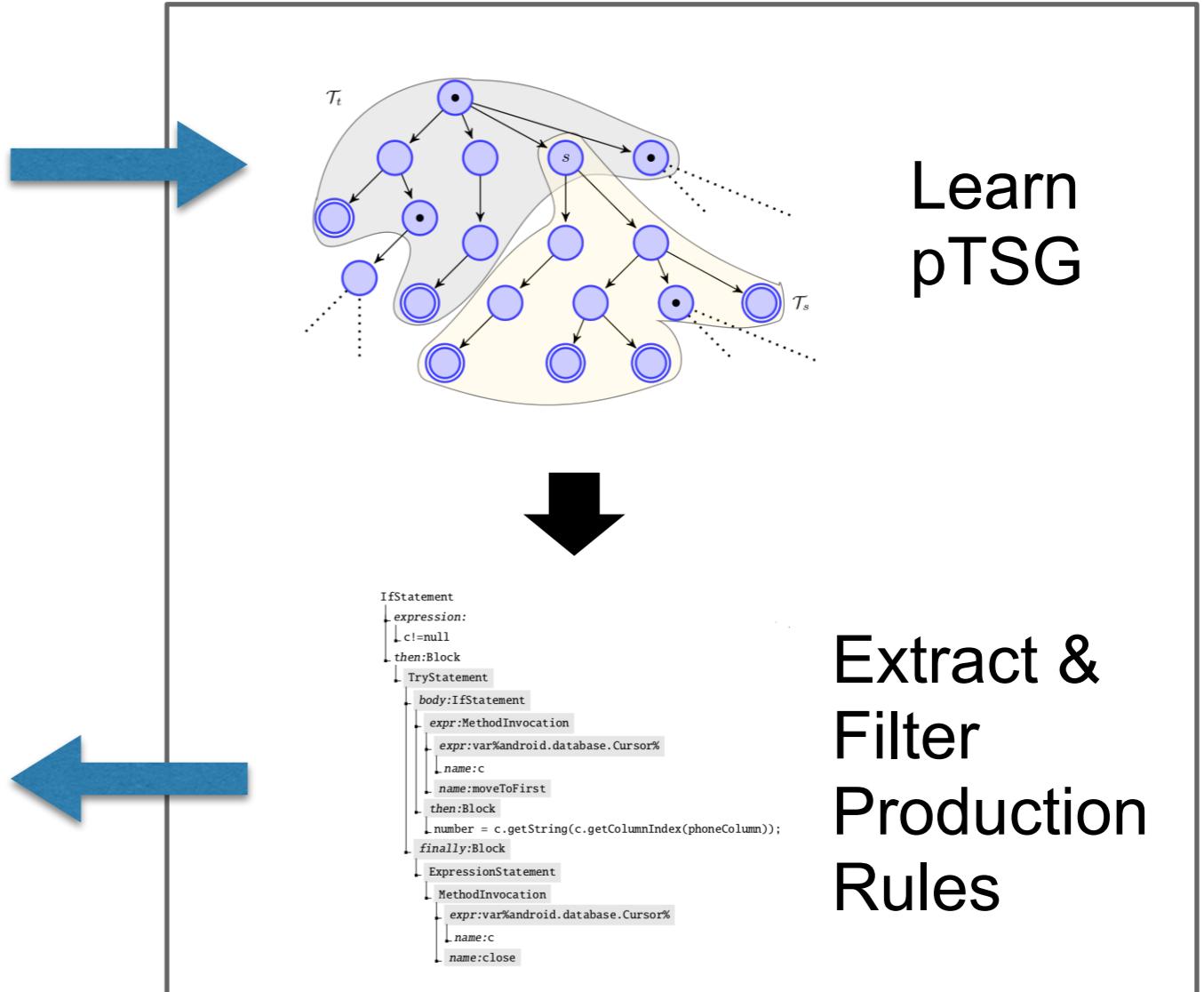
The Idiom Mining Problem

HAGGIS



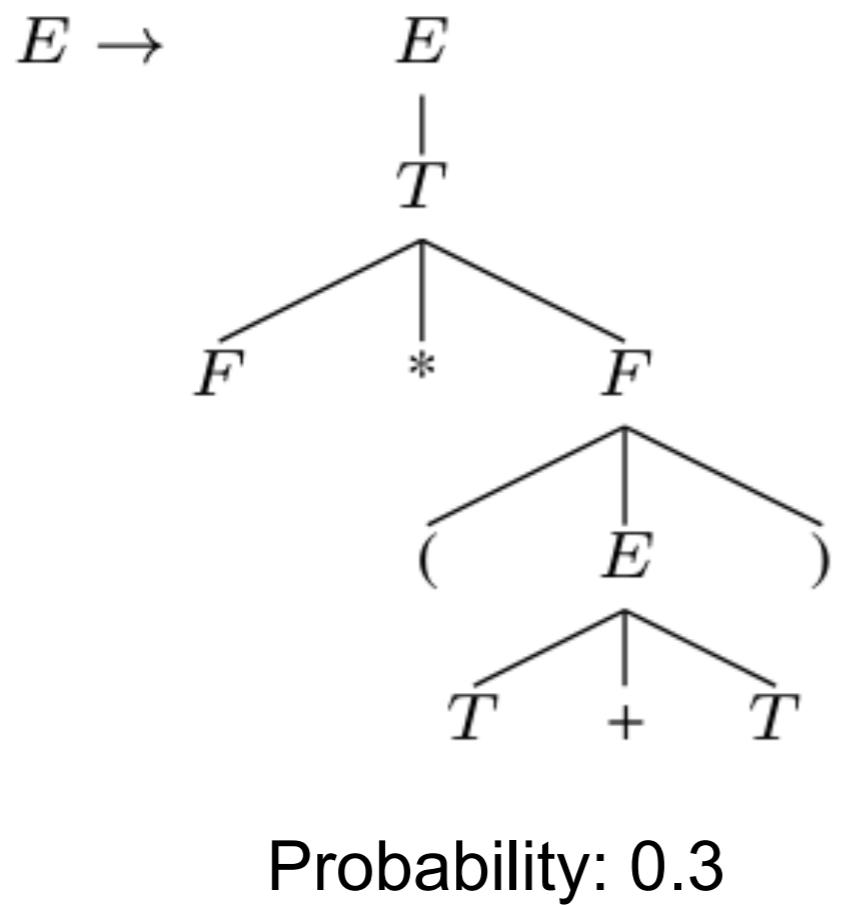
Idioms

```
try{  
    Node $name=$methodInvoc();  
    $BODY$  
}finally{  
    $(Transaction).finish();  
}  
  
Document doc=Jsoup.connect(URL).  
    userAgent("Mozilla").  
    header("Accept","text/html").  
    get();  
  
Toast.makeText(this,  
    $stringLit,Toast.LENGTH_SHORT)  
    .show()  
  
Location.distanceBetween(  
    $(Location).getLatitude(),  
    $(Location).getLongitude(),  
    $...);  
  
while (($String) = $(BufferedReader).  
    readLine()) != null) {  
    $BODY$  
}
```



Holistic, Automatic Gathering of
Grammatical Idioms from Software

Probabilistic TSGs



$E \rightarrow E + E$

Probability: 0.4

$E \rightarrow T$

Probability: 0.3

Given a CFG and corpus,
Infer elementary trees and
their probabilities

[Joshi and Schabes, 1997]

[Cohn et al, 2010]

[Post, and Gildea, 2009]

Inferring TSGs

Using Bayes Rule:

$$P(\theta | T_1 \dots T_N)$$

Posterior Distribution

θ : pTSG rules

Approximate using Markov Chain Monte Carlo

Type-based MCMC: [Liang, Jordan, Klein 2010]

Random code

```
public class JavaProjectionCalculator {  
    private boolean enableCollapsing;  
    public void setCollapsing(boolean collapseOn){  
        enableCollapsing=collapseOn;  
    }  
    public Map findAnnotations(IJavaElement parentElement){  
        try {  
            Throwables result=new HashMap();  
            findAnnotations((double)com.google.common.base.Preconditions.checkNotNull(result));  
            return result;  
        } catch (JavaModelException e) { }  
        return true;  
    }  
    private TSGNode findAnnotations(ProjectionAnnotation annotation, TableColumn  
result) throws JavaModelException {  
        int nextId;  
        int elemType=elem.getElementType();  
        Set regions=null;  
        try {  
            regions=computeProjections(annotation);  
        } catch ( RuntimeException e) {  
            e.printStackTrace();  
            throw e;  
        }  
        if (elem instanceof IParent) {  
            IJavaElement[] children=((IParent)owner).getChildren();  
            for (int fromPosition=0; i < children.length; i++) {  
                IJavaElement aChild=children[i];  
                Set childRegions=findAnnotations(aChild,result);  
            }  
        }  
    }  
}
```

Evaluation

- Qualitative analysis
- Precision and coverage in held out set
- External evaluation: StackOverflow
- Idioms and the real world: Eclipse SnipMatch

Projects Dataset

Name	Forks	Stars	Files	Description
arduino	2633	1533	180	Electronics Prototyping
atmosphere	1606	370	328	WebSocket Framework
bigbluebutton	1018	1761	760	Web Conferencing
elasticsearch	5972	1534	3525	REST Search Engine
grails-core	936	492	831	Web App Framework
hadoop	756	742	4985	Map-Reduce Framework
hibernate	870	643	6273	ORM Framework
libgdx	2903	2342	1985	Game Dev Framework
netty	2639	1090	1031	Net App Framework
storm	1534	7928	448	Distributed Computation
vert.x	2739	527	383	Application platform
voldemort	347	1230	936	NoSQL Database
wildfly	1060	1040	8157	Application Server

Library Dataset

Package Name	Files	Description
android.location	1262	Android location API
android.net.wifi	373	Android WiFi API
com.rabbitmq	242	Messaging system
com.spatial4j	65	Geospatial library
io.netty	65	Network app framework
opennlp	202	NLP tools
org.apache.hadoop	8467	Map-Reduce framework
org.apache.lucene	4595	Search Server
org.elasticsearch	338	REST Search Engine
org.eclipse.jgit	1350	Git implementation
org.hibernate	7822	Persistence framework
org.jsoup	335	HTML parser
org.mozilla.javascript	1002	JavaScript implementation
org.neo4j	1294	Graph database
twitter4j	454	Twitter API

Mined Idioms (General Java)

Iterate through the elements of an Iterator

```
for (Iterator iter=$methodInvoc;  
     iter.hasNext(); )  
{$BODY$}
```

Looping through lines from a BufferedReader

```
while (((String) = $(BufferedReader).  
        readLine()) != null) {  
    $BODY$  
}
```

Creating a logger for a class

```
private final static Log $name=  
    LogFactory.getLog($type.class);
```

Defining a String constant

```
public static final  
    String $name = $StringLit;
```

Mined Idioms (Library-Specific)

Database transaction in node4j

```
try{
  Node $name=$methodInvoc();
  $BODY$
}finally{
  $(Transaction).finish();
}
```

Get the distance between
two points in Android

```
Location.distanceBetween(
  $(Location).getLatitude(),
  $(Location).getLongitude(),
  $...);
```

Get an HTML Document in jsoup

```
Document doc=Jsoup.connect(URL).
  userAgent("Mozilla").
  header("Accept","text/html").
  get();
```

Show a small popup in Android

```
Toast.makeText(this,
  $stringLit,Toast.LENGTH_SHORT)
  .show()
```

Idioms in StackOverflow

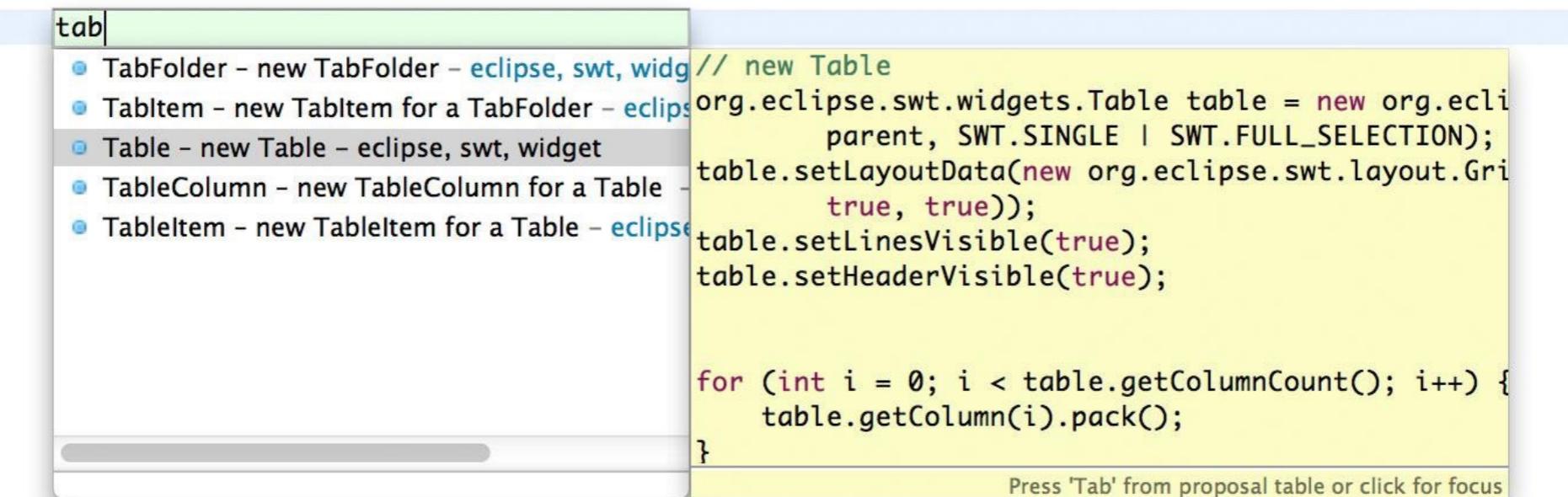


Test Corpus	Coverage	Precision
Stack Overflow	31%	67%
PROJECTS	22%	50%

Mined idioms are more common in example code

Eclipse SnipMatch

Currently contains ~100 human-created code snippets
(Eclipse Recommenders Project)



We submitted 44 snippets, of which:

- 19 already in SnipMatch
- 5 accepted
- 4 unsupported by tool
- 1 rejected as a bad practice
- 15 still waiting

Why patterns in software?

Orthogonal interfaces

Tools that “do one thing well” need to be combined well

Surface-semantic correspondence

Semantics available from *glancing* rather than *reading*

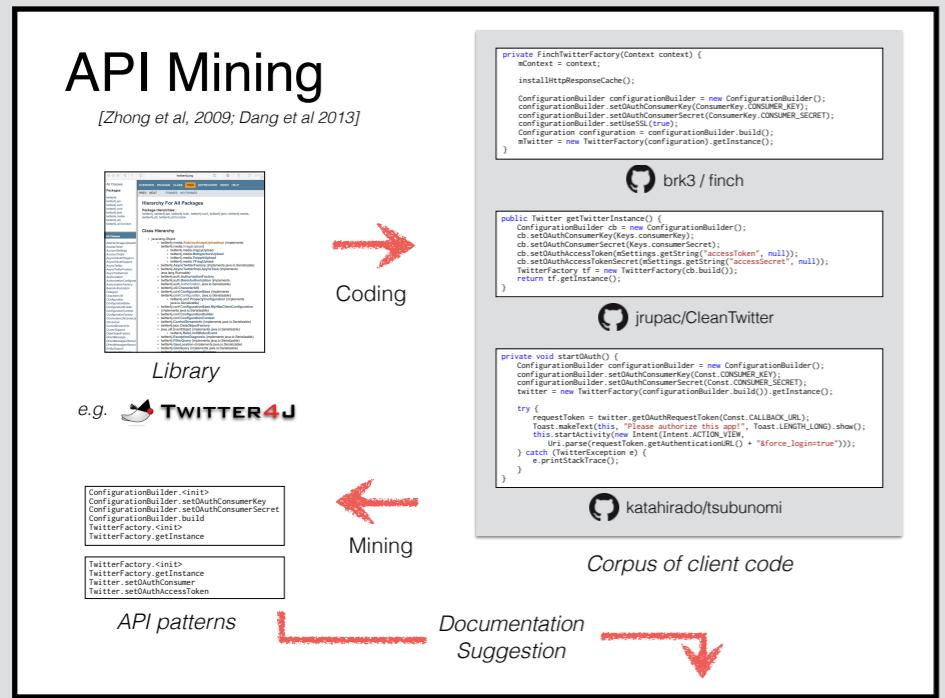
```
void addOne (int[] arr) {  
    for (int i = 0; i < arr.length; i++) {  
        arr[i] += 1;  
    }  
}
```

Natural code: Code with
good correspondence?

```
void foo (int[] bar) {  
    int baz = 0;  
    while (true) {  
        bar[baz] = bar[baz] + 1;  
        baz = baz + 1;  
        if (baz > bar.length) break;  
    }  
}
```

API Mining

[Zhong et al, 2009; Dang et al 2013]



API Mining from Github

Modern development is layers of libraries

Average Java file on Github:

Imports from **2.1** packages outside project

45% of files import an external package

(Not counting `java.*` `javax.*` `sun.*`)

Github Java corpus (Allamanis and Sutton, 2013)

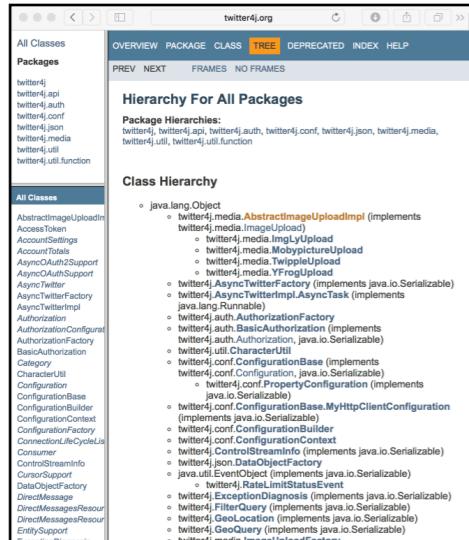
13000+ projects with at least one fork, 2M+ Java files

<http://groups.inf.ed.ac.uk/cup/javaGithub/>

(heuristic analysis)

API Mining

[Zhong et al, 2009; Dang et al 2013]



Library



```
ConfigurationBuilder.<init>
ConfigurationBuilder.setOAuthConsumerKey
ConfigurationBuilder.setOAuthConsumerSecret
ConfigurationBuilder.build
TwitterFactory.<init>
TwitterFactory.getInstance
```

```
TwitterFactory.<init>
TwitterFactory.getInstance
Twitter.setOAuthConsumer
Twitter.setOAuthAccessToken
```

API patterns

Coding

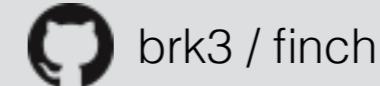


API Mining

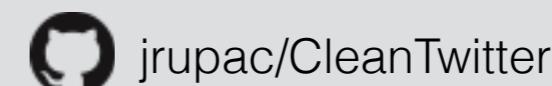
```
private FinchTwitterFactory(Context context) {
    mContext = context;

    installHttpCache();

    ConfigurationBuilder configurationBuilder = new ConfigurationBuilder();
    configurationBuilder.setOAuthConsumerKey(ConsumerKey.CONSUMER_KEY);
    configurationBuilder.setOAuthConsumerSecret(ConsumerKey.CONSUMER_SECRET);
    configurationBuilder.setUseSSL(true);
    Configuration configuration = configurationBuilder.build();
    mTwitter = new TwitterFactory(configuration).getInstance();
}
```

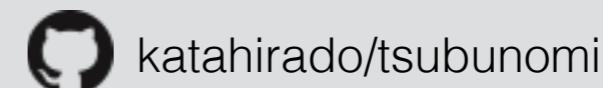


```
public Twitter getTwitterInstance() {
    ConfigurationBuilder cb = new ConfigurationBuilder();
    cb.setOAuthConsumerKey(Keys.consumerKey);
    cb.setOAuthConsumerSecret(Keys.consumerSecret);
    cb.setOAuthAccessToken(mSettings.getString("accessToken", null));
    cb.setOAuthAccessTokenSecret(mSettings.getString("accessSecret", null));
    TwitterFactory tf = new TwitterFactory(cb.build());
    return tf.getInstance();
}
```



```
private void startOAuth() {
    ConfigurationBuilder configurationBuilder = new ConfigurationBuilder();
    configurationBuilder.setOAuthConsumerKey(Const.CONSUMER_KEY);
    configurationBuilder.setOAuthConsumerSecret(Const.CONSUMER_SECRET);
    twitter = new TwitterFactory(configurationBuilder.build()).getInstance();

    try {
        requestToken = twitter.getOAuthRequestToken(Const.CALLBACK_URL);
        Toast.makeText(this, "Please authorize this app!", Toast.LENGTH_LONG).show();
        this.startActivity(new Intent(Intent.ACTION_VIEW,
            Uri.parse(requestToken.getAuthenticationURL() + "&force_login=true")));
    } catch (TwitterException e) {
        e.printStackTrace();
    }
}
```



Corpus of client code

Documentation
Suggestion



Frequent Sequence Mining

Return all patterns with \geq given support

[Agrawal and Srikant, 1995;
Wang and Han, 2004]

Support of pattern: Number of database
sequences that contain it

b **d** b a **f** e c
b c e a
e **d** a f c
a e f b
b **d** a e **f** c



Database of sequences

d a f c
b a f c
a e
b e
e c
...

Sequence patterns

(e.g. minimum support = 3)

Problem: Frequent can be trivial!

Fundamental Pathologies

Truncation

d a f c

Real pattern



a c

Could be returned
(more frequent!)

Spurious correlation

Support(a) = 90%

Support(d) = 90%

... but independent ...

d a

Pattern at 81%
min_support

Freerider

a f c real pattern

Support(d) = 90%

... but independent ...

a d f c

for high enough
min_support

Effect: Redundant
list of patterns

For API Mining...

*Top 10 API patterns
from pure sequence
mining (BIDE)*

TwitterFactory.<init>
TwitterFactory.getInstance

TwitterFactory.<init>
Twitter.setOAuthConsumer

Status.getUser
Status.getText

auth.AccessToken.<init>
Twitter.setOAuthAccessToken

TwitterFactory.<init>
TwitterFactory.getInstance
Twitter.setOAuthConsumer
Twitter.setOAuthAccessToken

TwitterFactory.getInstance
Twitter.setOAuthConsumer

TwitterFactory.<init>
TwitterFactory.getInstance
Twitter.setOAuthConsumer

TwitterFactory.<init>
Twitter.setOAuthAccessToken

TwitterFactory.<init>
TwitterFactory.getInstance
Twitter.setOAuthAccessToken

TwitterFactory.getInstance
Twitter.setOAuthAccessToken

TwitterFactory.<init>
Twitter.setOAuthConsumer
Twitter.setOAuthAccessToken

Previous Approach: Cluster before/after

[Zhong et al, 2009; Dang et al 2013]

Interesting Sequence Mining

define a goodness measure on a set of patterns

Minimum description length

[Vreeken et al, 2011; Tatti and Vreeken, 2012; Lam et al 2014]

Use patterns to define a compression algorithm for database

Search for patterns that best compress

Probabilistic methods

[Fowkes and Sutton, KDD 2016, PKDD 2016]

Use patterns to define a probability distribution over database

Search for patterns that maximise database probability

(actually isomorphic; see MacKay, 2003)

Sequences more meaningful, less redundant

Probabilistic Sequence Mining

[Fowkes and Sutton, KDD 2016]

Define a distribution $P(\text{ database} \mid \text{patterns})$

\mathcal{I}

[b c e]	:	0.1, 0.6
[d f]	:	0.7, 0.3
[d f]	:	0.8, 0.2
[e f]	:	0.8, 0.1

*Sequence patterns
(with probabilities)*



Sample

Inclusion variables:

$z_1: 1$

$z_2: 1$

$z_3: 1$

$z_4: 0$



Interleave
randomly

$X \ b \ d \ c \ e \ d \ f \ f$

Sampled database sequence

$$P(X, z | \mathcal{I})$$

probability of generating X, z
from this process

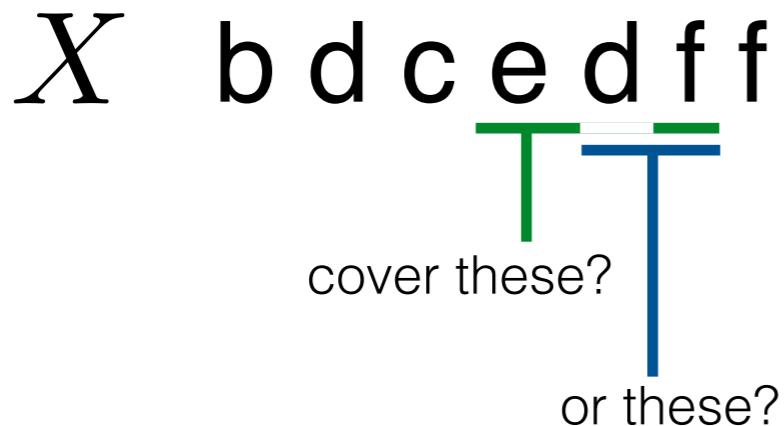
Probabilistic Sequence Mining

[Fowkes and Sutton, KDD 2016]

Model:

$$p(X, \mathbf{z} | \Pi) = \frac{1}{|\mathcal{P}|} \prod_{S \in \mathcal{I}} \prod_{m=0}^{|\pi_S|-1} \pi_{S_m}^{[z_S=m]}$$

Inference: Determine $z | X, \mathcal{I}$



\mathcal{I}

[b c e]	:	0.1, 0.6
[d f]	:	0.7, 0.3
[d f]	:	0.8, 0.2
[e f]	:	0.8, 0.1

Use greedy algorithm to

$$\max_z \log p(z | X, \mathcal{I})$$

(extension of weighted set cover)

Probabilistic Sequence Mining

[Fowkes and Sutton, KDD 2016]

Output of inference

	z	[b c e]	[d f]	[d f]	[e f]
b d c e d f f	1		1	1	0
e e d f f f	0		1	0	1
d f d d f f	0		1	1	1

Learning step: Infer \mathcal{I}

Update probabilities
(average of z)

Propose new patterns

Add to model

See if probability increases

\mathcal{I}

[b c e]	: 0.3, 0.7
[d f]	: 0.0, 1.0
[d f]	: 0.7, 0.3
[e f]	: 0.3, 0.7

Formally: Structural Expectation Maximization

Probabilistic API Miner (PAM)

Interesting sequence mining for API mining

```
ConfigurationBuilder.<init>
ConfigurationBuilder.setOAuthConsumerKey
ConfigurationBuilder.setOAuthConsumerSecret
ConfigurationBuilder.setUseSSL
ConfigurationBuilder.build
TwitterFactory.<init>
TwitterFactory.getInstance
```

```
ConfigurationBuilder.<init>
ConfigurationBuilder.setOAuthConsumerKey
ConfigurationBuilder.setOAuthConsumerSecret
ConfigurationBuilder.setOAuthAccessToken
ConfigurationBuilder.setOAuthAccessTokenSecret
ConfigurationBuilder.build
TwitterFactory.<init>
TwitterFactory.getInstance
```

```
ConfigurationBuilder.<init>
ConfigurationBuilder.setOAuthConsumerKey
ConfigurationBuilder.setOAuthConsumerSecret
ConfigurationBuilder.build
TwitterFactory.<init>
TwitterFactory.getInstance
TwitterFactory.getOAuthRequestToken
RequestToken.getAuthenticationURL
```

Sequence database

```
private FinchTwitterFactory(Context context) {
    mContext = context;
    installHttpCache();
    ConfigurationBuilder configurationBuilder = new ConfigurationBuilder();
    configurationBuilder.setOAuthConsumerKey(ConsumerKey.CONSUMER_KEY);
    configurationBuilder.setOAuthConsumerSecret(ConsumerKey.CONSUMER_SECRET);
    configurationBuilder.setUseSSL(true);
    Configuration configuration = configurationBuilder.build();
    mTwitter = new TwitterFactory(configuration).getInstance();
}
```

 brk3 / finch

```
public Twitter getTwitterInstance() {
    ConfigurationBuilder cb = new ConfigurationBuilder();
    cb.setOAuthConsumerKey(Keys.consumerKey);
    cb.setOAuthConsumerSecret(Keys.consumerSecret);
    cb.setOAuthAccessToken(mSettings.getString("accessToken", null));
    cb.setOAuthAccessTokenSecret(mSettings.getString("accessSecret", null));
    TwitterFactory tf = new TwitterFactory(cb.build());
    return tf.getInstance();
}
```

 jrupac/CleanTwitter

```
private void startOAuth() {
    ConfigurationBuilder configurationBuilder = new ConfigurationBuilder();
    configurationBuilder.setOAuthConsumerKey(Const.CONSUMER_KEY);
    configurationBuilder.setOAuthConsumerSecret(Const.CONSUMER_SECRET);
    twitter = new TwitterFactory(configurationBuilder.build()).getInstance();

    try {
        requestToken = twitter.getOAuthRequestToken(Const.CALLBACK_URL);
        Toast.makeText(this, "Please authorize this app!", Toast.LENGTH_LONG).show();
        this.startActivity(new Intent(Intent.ACTION_VIEW,
            Uri.parse(requestToken.getAuthenticationURL() + "&force_login=true")));
    } catch (TwitterException e) {
        e.printStackTrace();
    }
}
```

 katahirado/tsubunomi

Corpus



*Probabilistic
sequence mining*

Data

Target projects: 17 Java libraries, all that:

Library source on Github

Library in top 1000 Github projects

Called by >50 other methods on Github

At least 10k lines of `example/` code

Total: Over 300k lines of example code

Client methods: all that called any targets

967 client projects

Total: Over 4M lines of client code

Experimental Questions

Quality

Match to “held-out” client code

Match to examples from library developers

Measure: sequence overlap, precision, recall

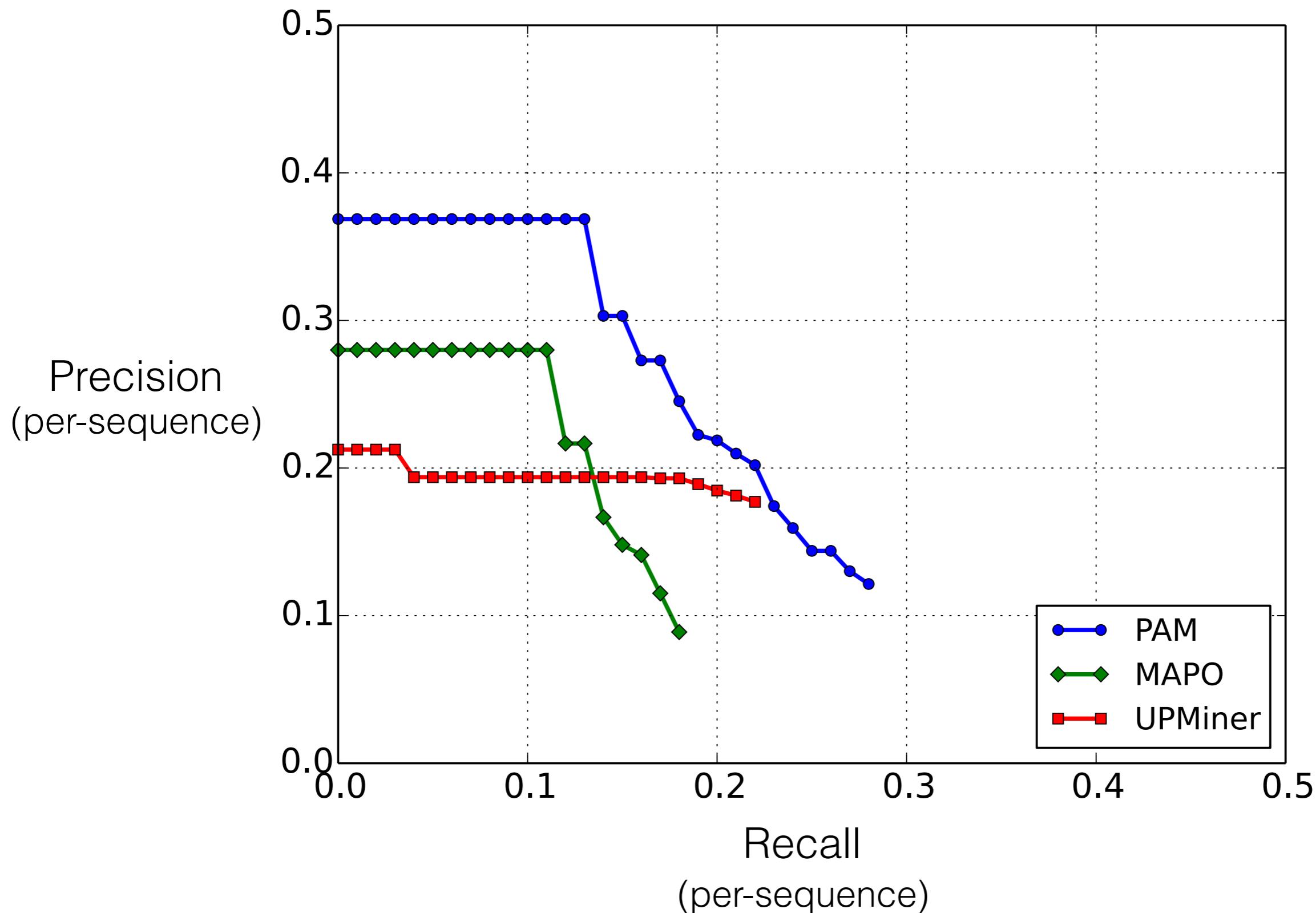
Redundancy

Why? Ease of use, diversity

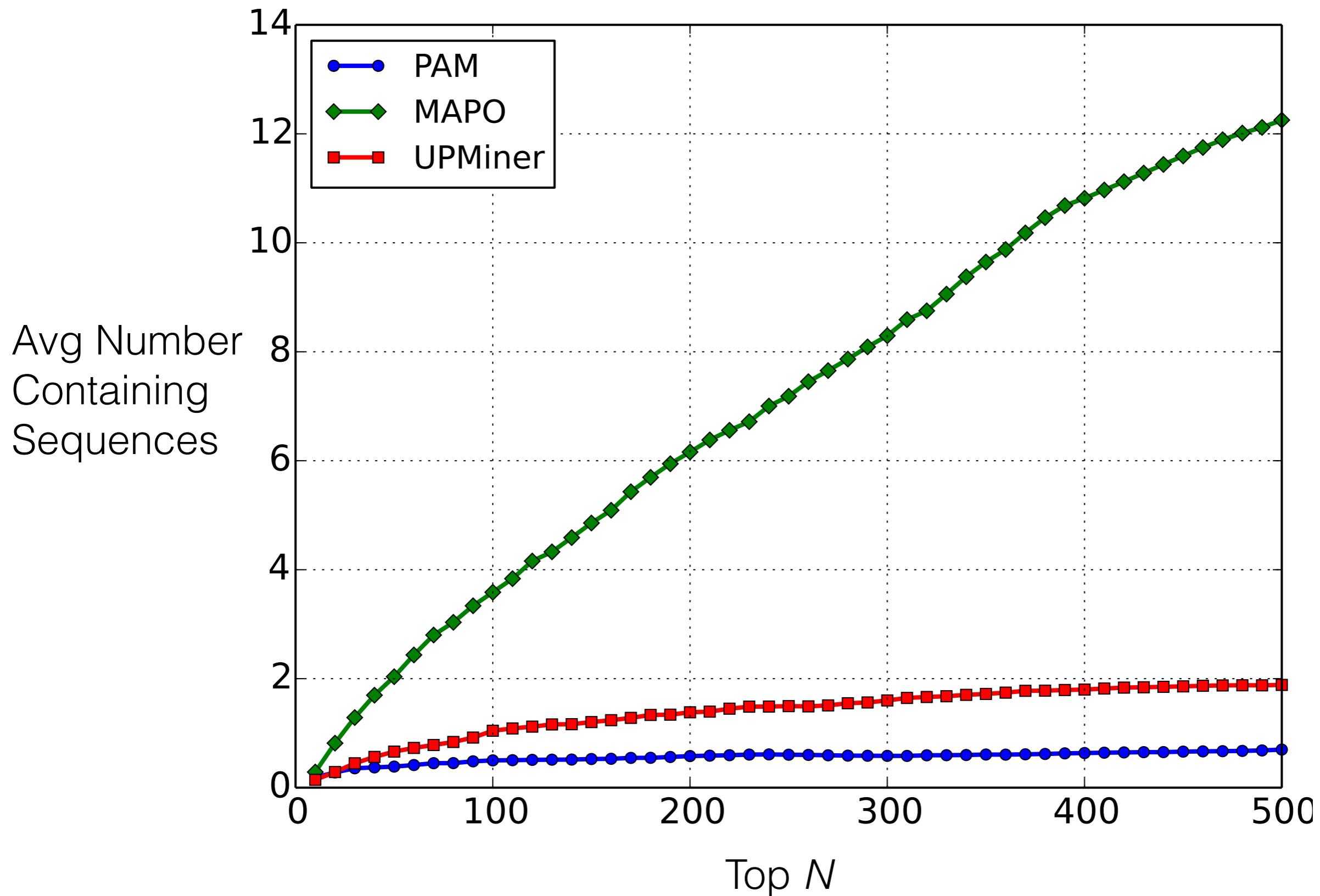
Measure: number of containing sequences

All results averaged over the 17 libraries

Handwritten Examples



Redundancy



Example: twitter4j

PAM

TwitterFactory.<init>
TwitterFactory.getInstance

TwitterFactory.<init>
TwitterFactory.getInstance
Twitter.setOAuthConsumer
Twitter.setOAuthAccessToken

Status.getUser
Status.getText

AccessToken.getToken
AccessToken.getTokenSecret

ConfigurationBuilder.<init>
ConfigurationBuilder.build
TwitterFactory.<init>
TwitterFactory.getInstance

MAPO

[Zhong et al, '09]

TwitterFactory.<init>
TwitterFactory.getInstance

Status.getUser
Status.getText

ConfigurationBuilder.<init>
ConfigurationBuilder.build

ConfigurationBuilder.<init>
TwitterFactory.<init>

ConfigurationBuilder.<init>
ConfigurationBuilder.setOAuthConsumerKey

UPMiner

[Wang et al, '13]

TwitterFactory.<init>
TwitterFactory.getInstance

TwitterFactory.getInstance
Twitter.setOAuthConsumer

TwitterFactory.<init>
TwitterFactory.getInstance
Twitter.setOAuthConsumer

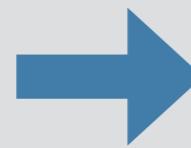
Status.getUserStatus.getText

Twitter.setOAuthConsumer
Twitter.setOAuthAccessToken



: two main types of twitter initialization call

```
1 /* Header */
2 package org.zoolu.sip.header;
3
4 /** SIP Status-line, i.e. the first
5 * line of a response message */
6 public class StatusLine {
7 protected int code;
8 protected String reason;
9
10 /** Construct StatusLine */
11 public StatusLine(int c, String r) {
12 code = c;
13 reason = r;
14 }
15
16 /** Create a new copy of the request-line */
17 public Object clone() {
18 return new StatusLine(getCode(), getReason());
19 }
20
21 /** Indicates whether some other Object
22 * is "equal to" this StatusLine */
23 public boolean equals(Object obj){
24 try {
25 StatusLine r = (StatusLine) obj;
26 if (r.getCode() == getCode()&&
27 r.getReason().equals(getReason()))
28 return true;
29 else
30 return false;
31 } catch (Exception e) {
32 return false;
33 }
34 }
35
36 public int getCode() {
37 return code;
38 }
39
40 public String getReason() {
41 return reason;
42 }
43
44 public String toString() {
45 return "SIP/2.0 " + code + " " + reason + "\r\n";
46 }
47}
```



```
1 /* Header...*/
2 package org.zoolu.sip.header;
3
4 /** SIP Status-line, i.e. the first... */
5 public class StatusLine {
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20 r.getReason().equals(getReason()))
21 return true;
22 else
23 return false;
24 } catch (Exception e) {...}
25
26 public int getCode() {...}
27
28 public String getReason() {...}
29
30 public String toString() {...}
31}
```

Code summarisation

```

1 /* Header */
2 package org.zoolu.sip.header;
3
4 /** SIP Status-line, i.e. the first
5  * line of a response message */
6 public class StatusLine {
7     protected int code;
8     protected String reason;
9
10    /** Construct StatusLine */
11    public StatusLine(int c, String r) {
12        code = c;
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14    }
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16    /** Create a new copy of the request-line */
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18        return new StatusLine(getCode(), getReason());
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21    /** Indicates whether some other Object
22     * is "equal to" this StatusLine */
23    public boolean equals(Object obj){
24        try {
25            StatusLine r = (StatusLine) obj;
26            if (r.getCode() == getCode()&&
27                r.getReason().equals(getReason()))
28                return true;
29            else
30                return false;
31        } catch (Exception e) {
32            return false;
33        }
34    }
35
36    public int getCode() {
37        return code;
38    }
39
40    public String getReason() {
41        return reason;
42    }
43
44    public String toString() {
45        return "SIP/2.0 " + code + " " + reason + "\r\n";
46    }
47 }

```

statusline.java from BigBlueButton

```

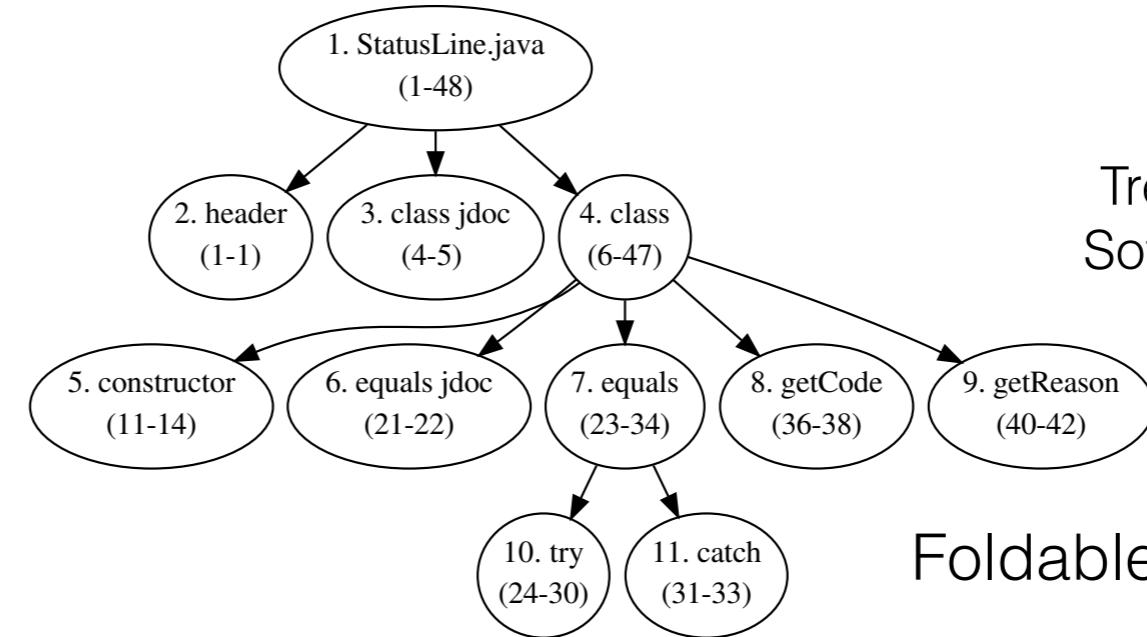
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5 public class StatusLine {
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10    /** Construct StatusLine...*/
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36    public int getCode() {...}
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44    public String toString() {...}
47 }

```

TASSAL

Tree-based Autofolding
Software Summarization
ALgorithm

```
1 /* Header */
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44 public String toString() {
45 return "SIP/2.0 " + code + " " + reason + "\r\n";
46 }
47 }
```



Foldable Tree

File



Bag of “words”

Optimization

match unfolded nodes
to file topic

src connection “File” topic
bean spring “Project” topic
get value “Java” topic

TopicSum

[Haghghi and Vanderwende, 2009]

Example topics

Background	Project		File	
	spring-framework	bigbluebutton	DataSourceUtils	QuaLsp
get	bean	sip	connection	lsp
string	org	org	con	j
value	test	log	holder	constants
name	context	it	source	k
type	springframework	event	data	ld8
object	exception	gnu	synchronization	mode
i	request	listener	isolation	tmp

Developer Study

	Conciseness	Usefulness
Gold	3.34	3.33
TASSAL	3.27	3.18
Javadocs	3.07	2.69
Shallowest	2.97	2.50
Largest	3.08	2.67

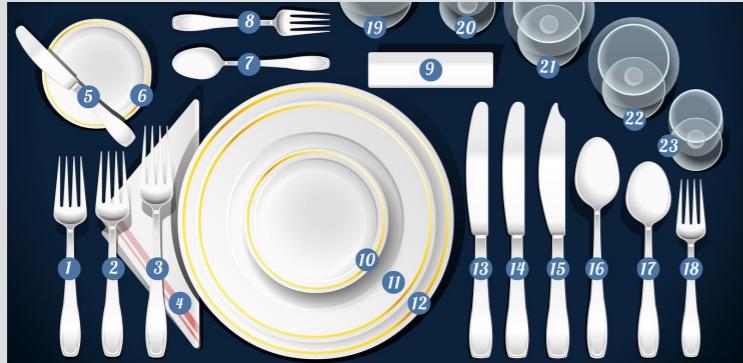
Six developers. Avg 4 years industry experience. 1...5 Likert scale

Statistical Analysis of Computer Program Text

Charles Sutton, University of Edinburgh

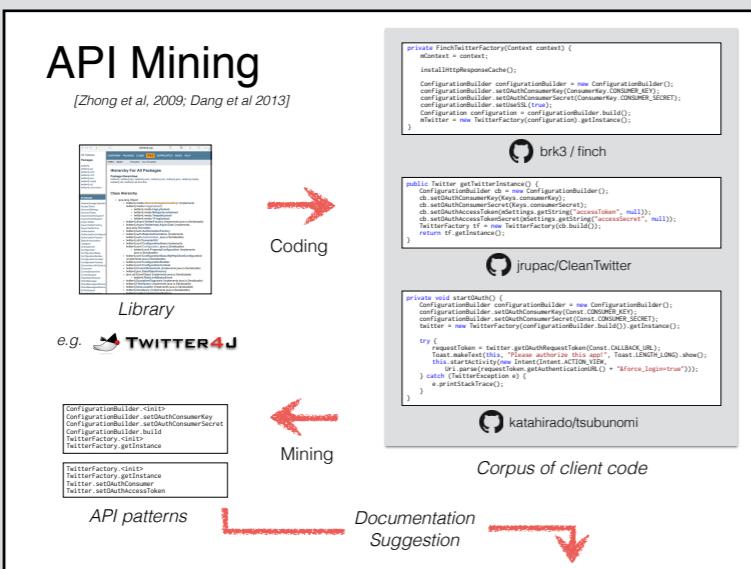
Companion web site

<http://bit.ly/sutton-nlpswe>



Our other related research

<https://mast-group.github.io>



```
/* Header */
package org.zoolu.sip.header;

// SIP Status-line, i.e. the first
// line of a response message
public class StatusLine {
    protected int code;
    protected String reason;

    /* Constructor */
    public StatusLine(int c, String r) {
        code = c;
        reason = r;
    }

    /* Create a new copy of the request-line */
    public Object clone() {
        return new StatusLine(getCode(), getReason());
    }

    /* Indicates whether some other Object
     * is equal to this StatusLine */
    public boolean equals(Object obj) {
        try {
            StatusLine r = (StatusLine) obj;
            if (r.getCode() == getCode() &
                r.getReason().equals(getReason()))
                return true;
            else
                return false;
        } catch (Exception e) {
            return false;
        }
    }

    public int getCode() {
        return code;
    }

    public String getReason() {
        return reason;
    }

    public String toString() {
        return SIP/2.0 " + code + " " + reason + "\r\n";
    }
}
```

Thanks!

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Engineering and Physical Sciences
Research Council