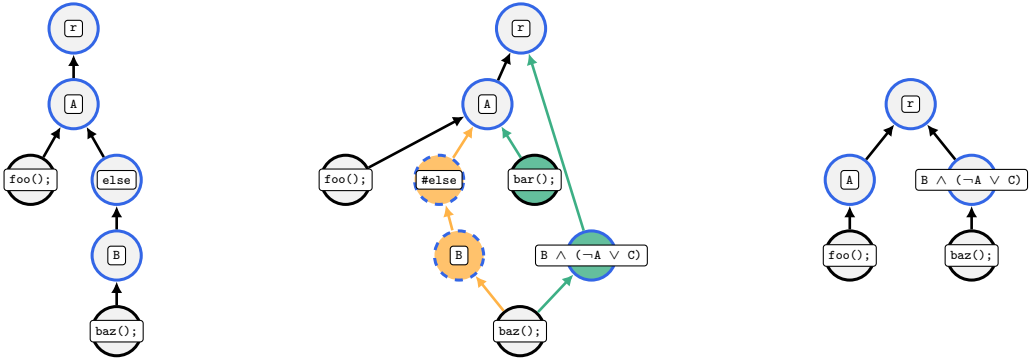


Classifying Edits to Variability in Source Code

Paul Bittner, Christof Tinnes, Alexander Schultheiß, Sören Viegener, Timo Kehrer, and Thomas Thüm | Nov 14, 2022

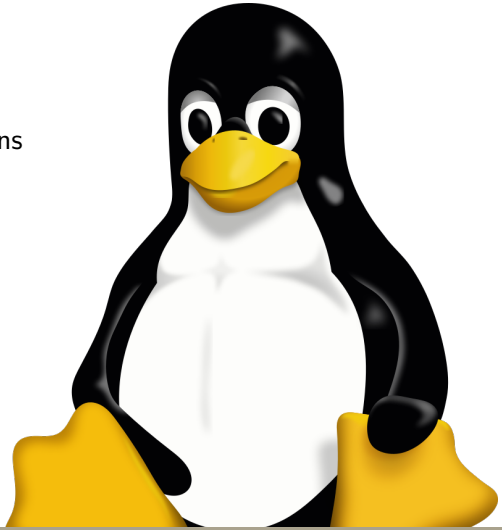
universität ulm

Software Comprises Massive Evolving Variability

$\geq$ **12,000**
configuration options

$\geq$ $\mathbf{10^{5000}}$
different variants

[2016]



Software Comprises Massive Evolving Variability

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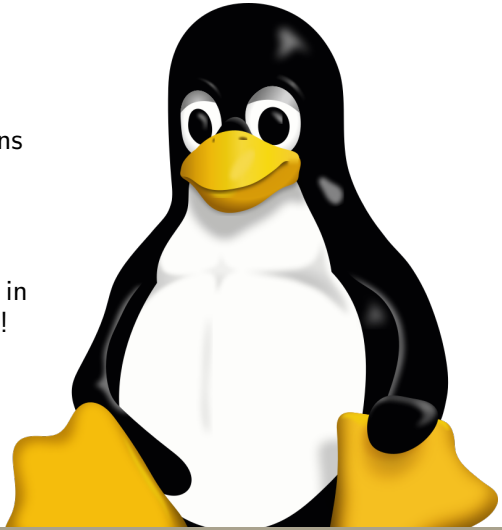
Only $\sim\mathbf{10^{80}}$ atoms in observable universe!

[2016]



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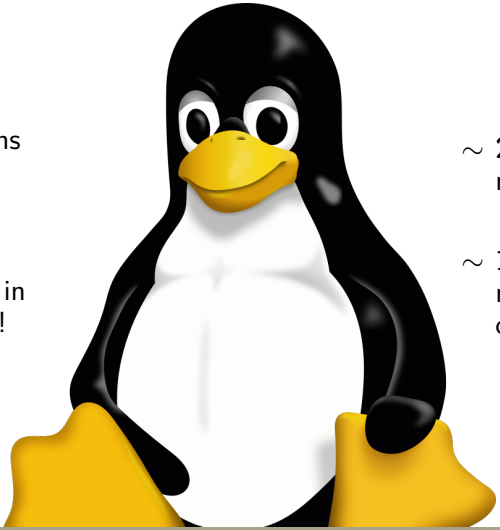

$\sim$ **21,000**
new LOC / week

$\sim$ **15**
new configuration options / week

Variability via C Preprocessor

```
   static void
f_foreground(/* params */)
{
#ifdef FEAT_GUI
   if (gui.in_use)
   gui_mch_set_foreground();
#else
# ifdef MSWIN
   win32_set_foreground();
# endif
#endif
}
```

Vim Commit ab4cece.

Variability via C Preprocessor

```c
   static void
f_foreground(/* params */)
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# endif
#endif
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```

FEAT_GUI

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¬FEAT_GUI, MSWIN →

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¬FEAT_GUI, ¬MSWIN →

```
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f_foreground(/* params */)
{
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```

Vim Commit ab4cece.

Edits to Variability via C Preprocessor

```
#ifdef A
 foo();
#else
 #ifdef B
 baz();
 #endif
#endif
```

Example simplified from Vim commit afde13b.

Edits to Variability via C Preprocessor

```
#ifdef A
 foo();
#else
 #ifdef B
 baz();
 #endif
#endif
```

Commit afde13b →

```
#ifdef A
 foo();
 bar();
#endif
#if B && (!A || C)
 baz();
#endif
```

Example simplified from Vim commit afde13b.

Edits to Variability via C Preprocessor

```
#ifdef A
 foo();
#else
 #ifdef B
 baz();
 #endif
#endif
```

```
 #ifdef A
  foo();
-#else
-  #ifdef B
+  bar();
+#endif
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-  #endif
 #endif
```

```
#ifdef A
 foo();
 bar();
#endif
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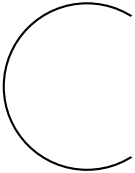
#endif
```

Example simplified from Vim commit afde13b.

Related Work on Edit Classification is . . .

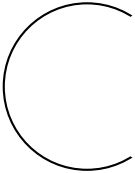
incomplete



[Stănciulescu et al., 2016]
[Borba et al., 2012]
[Al-Hajjaji et al., 2016]
[Passos et al., 2016]

Related Work on Edit Classification is . . .

incomplete **or** **ambiguous**



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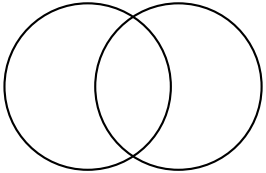
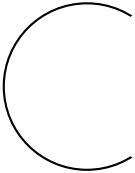


[Ji et al., 2015]
[Stănciulescu et al., 2016]

Related Work on Edit Classification is . . .

incomplete or **ambiguous** or **not automatable**



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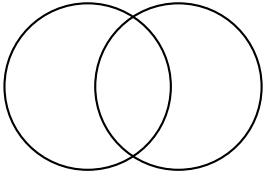

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```
#ifdef A
  foo();
#else
  #ifdef B
  baz();
  #endif
#endif
```

diff

```
  #ifdef A
    foo();
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+   bar();
+#endif
+#if B && (!A || C)
    baz();
-   #endif
  #endif
```

diff

```
#ifdef A
  foo();
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```

Research Goal:
complete, unambiguous, and automatable
model and classification

?

Classification

```
#ifdef A
  foo();
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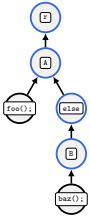
  #ifdef B
  baz();
  #endif
#endif
```

parse



First, we introduce *Variation Trees* as a model for variability in source code.

diff

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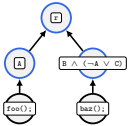

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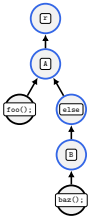
parse



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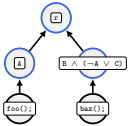

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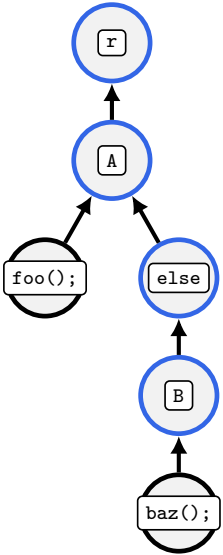

diff

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  foo();
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  baz();
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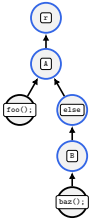

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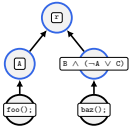

Edits to variability become edits to Variation Trees

```
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```

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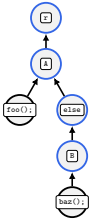

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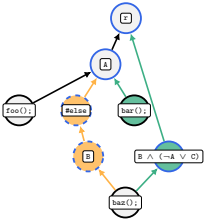

diff

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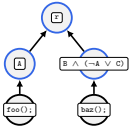

Edits to variability become edits to Variation Trees, for which we introduce *Variation Diffs*.

```
#ifdef A
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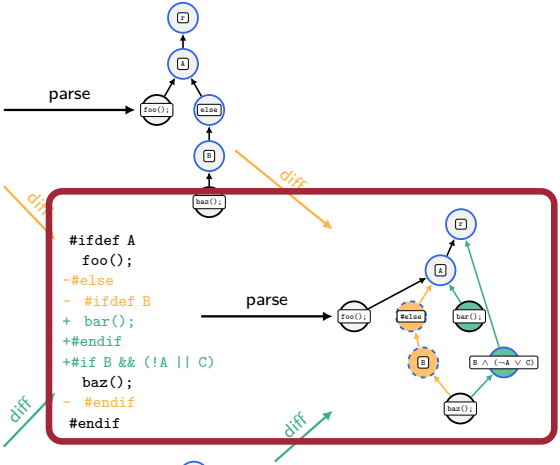
  #endif
#endif
```

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```

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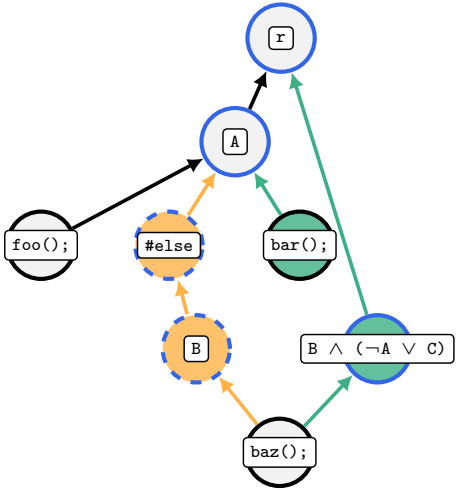

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```

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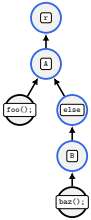

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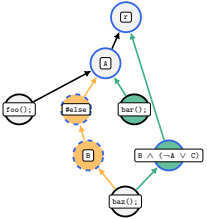

diff

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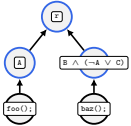
```

parse



```
#ifdef A
  foo();
#else
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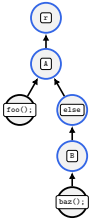
  baz();
  #endif
#endif
```

parse



diff

```
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+   bar();
+#endif
+#if B && (!A || C)
    baz();
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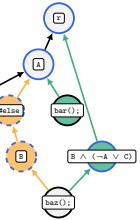
  #endif
```

parse



classify

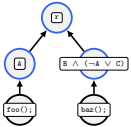
diff

diff

diff

```
#ifdef A
  foo();
  bar();
#endif
#if B && (!A || C)
  baz();
#endif
```

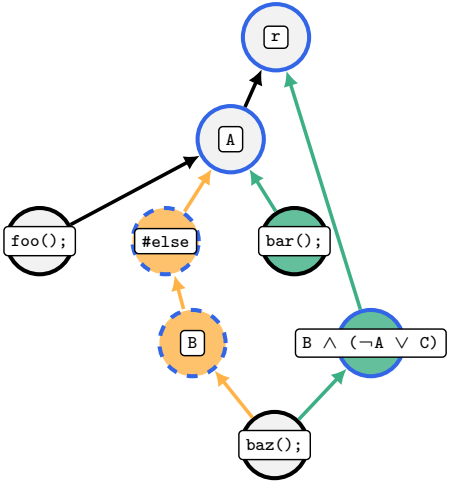
parse



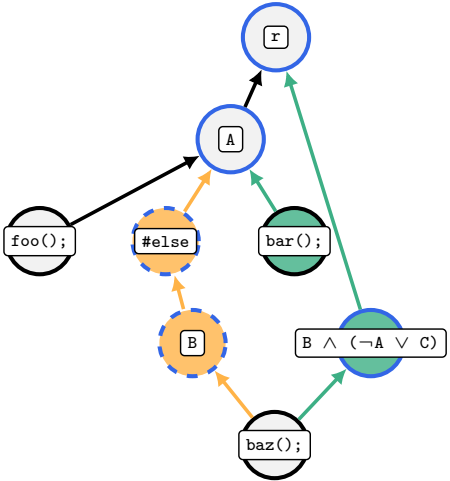
Classifying Edits to Variability in Source Code

reduces to

Classifying Structures in Variation Diffs

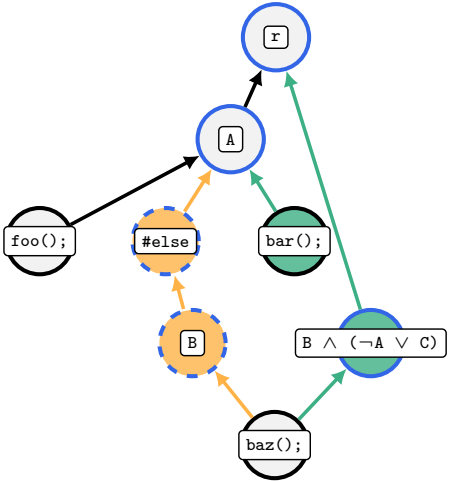


is unchanged



is unchanged

is added to feature A



is unchanged

is added to feature A

is moved
from $B \wedge \neg A$
to $B \wedge (\neg A \vee C)$

Classification $:=$ Set of Classes

Classification := Set of Classes

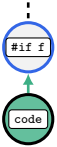
$class : \boxed{\text{code}} \rightarrow \{true, false\}$

Classification := Set of Classes

$class : \textcircled{\boxed{\texttt{code}}} \rightarrow \{true, false\}$

Example:

$$AddToPC(\textcircled{\boxed{\texttt{code}}}) := \text{added}(\textcircled{\boxed{\texttt{code}}}) \wedge \neg\, \text{added}(p_a(\textcircled{\boxed{\texttt{code}}}))$$



We define 9 classes.

AddWithMapping(c) := added(c) ∧ added$(M_a(c))$

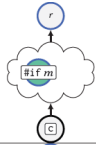
```
+ #if m
+   c
+ #endif
```

AddToPC(c) := added(c) ∧ ¬ added$(M_a(c))$

```
  #if m
+   c
  #endif
```

Specialization(c) := unchanged(c)
∧¬(PC$_b(c)$ ⊨ PC$_a(c)$)
∧ (PC$_a(c)$ ⊨ PC$_b(c)$)

```
+ #if m
    c
+ #endif
```



RemWithMapping(c) := removed(c) ∧ removed$(M_b(c))$

```
- #if m
-   c
- #endif
```

RemFromPC(c) := removed(c) ∧ ¬ removed$(M_b(c))$

```
  #if m
-   c
  #endif
```

Generalization(c) := unchanged(c)
∧ (PC$_b(c)$ ⊨ PC$_a(c)$)
∧¬(PC$_a(c)$ ⊨ PC$_b(c)$)

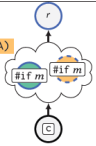
```
- #if m
    c
- #endif
```

Reconfiguration(c) := unchanged(c)
∧¬(PC$_b(c)$ ⊨ PC$_a(c)$)
∧¬(PC$_a(c)$ ⊨ PC$_b(c)$)

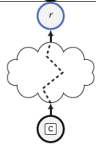
```
- #if m
+ #if m'
    c
  #endif
```

Refactoring(c) := unchanged(c)
∧(PC$_b(c)$ ⊨ PC$_a(c)$)
∧(PC$_a(c)$ ⊨ PC$_b(c)$)
∧($path_b(c) \neq path_a(c)$)

```
- #if A || (B && !A)
+ #if A || B
    c
  #endif
```



Untouched(c) := unchanged(c)
∧(PC$_b(c)$ ⊨ PC$_a(c)$)
∧(PC$_a(c)$ ⊨ PC$_b(c)$)
∧($path_b(c) = path_a(c)$)



We define 9 classes.

AddWithMapping(c) := added(c) ∧ added$(M_a(c))$

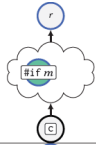
```
+ #if m
+   c
+ #endif
```

AddToPC(c) := added(c) ∧ ¬ added$(M_a(c))$

```
  #if m
+   c
  #endif
```

Specialization(c) := unchanged(c)
∧¬(PC$_b(c)$ ⊨ PC$_a(c)$)
∧ (PC$_a(c)$ ⊨ PC$_b(c)$)

```
+ #if m
  c
+ #endif
```



RemWithMapping(c) := removed(c) ∧ removed$(M_b(c))$

```
- #if m
-   c
- #endif
```

RemFromPC(c) := removed(c) ∧ ¬ removed$(M_b(c))$

```
  #if m
-   c
  #endif
```

Generalization(c) := unchanged(c)
∧ (PC$_b(c)$ ⊨ PC$_a(c)$)
∧¬(PC$_a(c)$ ⊨ PC$_b(c)$)

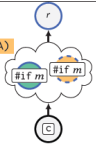
```
- #if m
  c
- #endif
```

Reconfiguration(c) := unchanged(c)
∧¬(PC$_b(c)$ ⊨ PC$_a(c)$)
∧¬(PC$_a(c)$ ⊨ PC$_b(c)$)

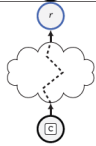
```
- #if m
+ #if m'
  c
  #endif
```

Refactoring(c) := unchanged(c)
∧(PC$_b(c)$ ⊨ PC$_a(c)$)
∧(PC$_a(c)$ ⊨ PC$_b(c)$)
∧($path_b(c) \neq path_a(c)$)

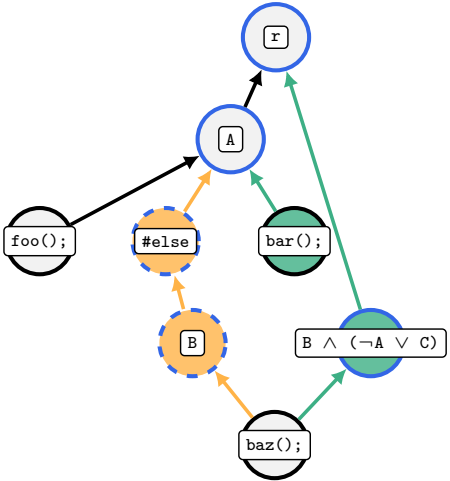
```
- #if A || (B && !A)
+ #if A || B
  c
  #endif
```



Untouched(c) := unchanged(c)
∧(PC$_b(c)$ ⊨ PC$_a(c)$)
∧(PC$_a(c)$ ⊨ PC$_b(c)$)
∧($path_b(c) = path_a(c)$)



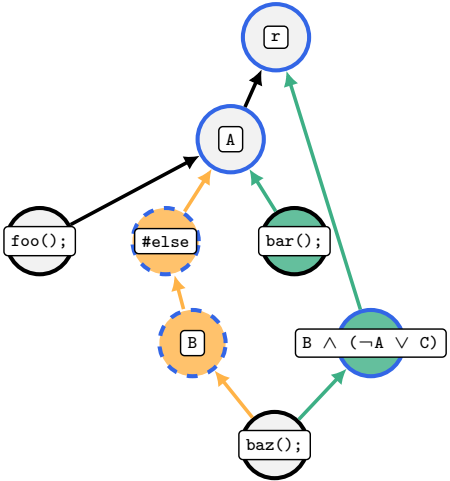
Custom classifications possible.



is unchanged

is added to feature A

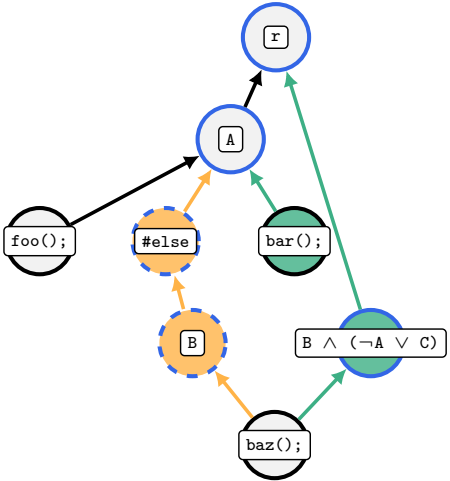
is moved
from $B \wedge \neg A$
to $B \wedge (\neg A \vee C)$



is unchanged

$AddToPC($  $) = true$

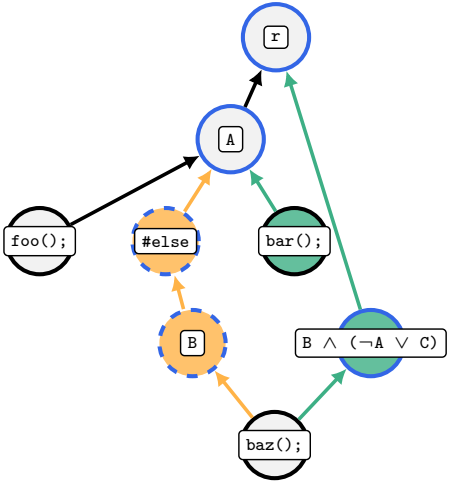
is moved
from $B \wedge \neg A$
to $B \wedge (\neg A \vee C)$



Untouched(`foo();`) = *true*

AddToPC(`bar();`) = *true*

`baz();` is moved
from $B \wedge \neg A$
to $B \wedge (\neg A \vee C)$



Untouched(foo();) = *true*

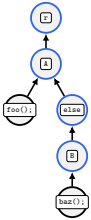
AddToPC(bar();) = *true*

Generalization(baz();) = *true*

because $B \wedge \neg A \models B \wedge (\neg A \vee C)$

```
#ifdef A
  foo();
#else
  #ifdef B
  baz();
  #endif
#endif
```

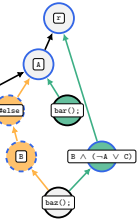
parse



diff

```
#ifdef A
  foo();
-#else
-  #ifdef B
+  bar();
+#endif
+#if B && (!A || C)
  baz();
-  #endif
#endif
```

parse



classify

Untouched(foo();) = *true*

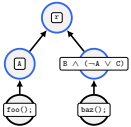
AddToPC(bar();) = *true*

Generalization(baz();) = *true*

diff

```
#ifdef A
  foo();
  bar();
#endif
#if B && (!A || C)
  baz();
#endif
```

parse

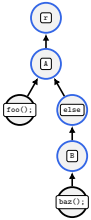


diff

Analytical Evaluation

```
#ifdef A
  foo();
#else
  #ifdef B
  baz();
  #endif
#endif
```

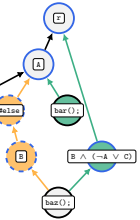
parse



diff

```
  #ifdef A
    foo();
-#else
-   #ifdef B
+   bar();
+#endif
+#if B && (!A || C)
    baz();
-   #endif
  #endif
```

parse



classify

$Untouched($ foo(); $) = true$

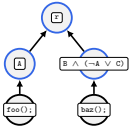
$AddToPC($ bar(); $) = true$

$Generalization($ baz(); $) = true$

diff

```
#ifdef A
  foo();
  bar();
#endif
#if B && (!A || C)
  baz();
#endif
```

parse



Analytical Evaluation

```
#ifdef A
  foo();
#else
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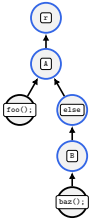
  baz();
  #endif
#endif
```

parse



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  #ifdef A
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+#endif
+#if B && (!A || C)
    baz();
-   #endif
  #endif
```

diff

```
#ifdef A
  foo();
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#endif
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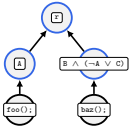
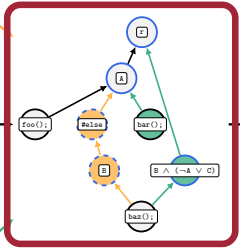
#endif
```

parse



diff

parse



classify

Untouched(foo();) = *true*

AddToPC(bar();) = *true*

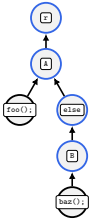
Generalization(baz();) = *true*

We prove completeness ◯ and soundness. □

Analytical Evaluation

```
#ifdef A
  foo();
#else
  #ifdef B
  baz();
  #endif
#endif
```

parse



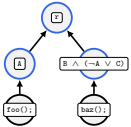
diff

```
  #ifdef A
    foo();
-#else
-   #ifdef B
+   bar();
+#endif
+#if B && (!A || C)
    baz();
-   #endif
  #endif
```

diff

```
#ifdef A
  foo();
  bar();
#endif
#if B && (!A || C)
  baz();
#endif
```

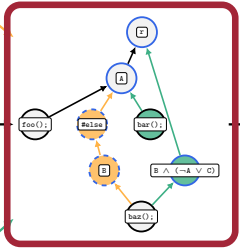
parse



diff

diff

parse



We prove completeness ◯ and soundness. □

classify

Untouched(foo();) = *true*

AddToPC(bar();) = *true*

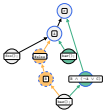
Generalization(baz();) = *true*

We prove completeness ◯ and unambiguity ◯◯. □

From Theory to Practice

44 open-source system histories (incl. 🐧)

Parse all Patches to



Success → Classify (RG_2) → Count Class Occurrences (RG_3)

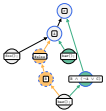
Failure → Inspect Failure (RG_1)

From Theory to Practice

44 open-source system histories (incl. 🐧)

1.7 million commits
45 million edits

Parse all Patches to



Success → Classify (RG_2) → Count Class Occurrences (RG_3)

Failure → Inspect Failure (RG_1)

From Theory to Practice

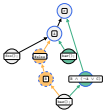
Measure Runtime (RG_4)

git

44 open-source system histories (incl. 🐧)

1.7 million commits
45 million edits

Parse all Patches to



Success

Failure

Classify (RG_2)

Count Class Occurrences (RG_3)

Inspect Failure (RG_1)

From Theory to Practice

RG_1 Variation Diffs Validate completeness of variation diffs.

From Theory to Practice

RG_1 Variation Diffs Validate completeness of variation diffs.

Result All patches with syntactically correct variability annotations can be parsed (99.82%). ✓ $\Rightarrow$ ◯

From Theory to Practice

RG_1 Variation Diffs	Validate completeness of variation diffs.
Result	All patches with syntactically correct variability annotations can be parsed (99.82%). ✓ ⇒ ◯
RG_2 Classification	Validate completeness and unambiguity of classification.

From Theory to Practice

RG_1	**Variation Diffs**	Validate completeness of variation diffs.
	Result	All patches with syntactically correct variability annotations can be parsed (99.82%). ✓ $\Rightarrow$ ◯
RG_2	**Classification**	Validate completeness and unambiguity of classification.
	Result	All edits were assigned exactly one class. ✓ $\Rightarrow$ ◯ $\wedge$ ◯◯

From Theory to Practice

RG_1	**Variation Diffs**	Validate completeness of variation diffs.
	Result	All patches with syntactically correct variability annotations can be parsed (99.82%). ✓ $\Rightarrow$ ◯
RG_2	**Classification**	Validate completeness and unambiguity of classification.
	Result	All edits were assigned exactly one class. ✓ $\Rightarrow$ ◯ $\wedge$ ◯◯
RG_3	**Relevancy**	Validate that our edit classes are relevant (i.e., all classes occur in practice).

From Theory to Practice

RG_1	**Variation Diffs**	Validate completeness of variation diffs.
	Result	All patches with syntactically correct variability annotations can be parsed (99.82%). ✓ $\Rightarrow$ ◯
RG_2	**Classification**	Validate completeness and unambiguity of classification.
	Result	All edits were assigned exactly one class. ✓ $\Rightarrow$ ◯ $\wedge$ ◯◯
RG_3	**Relevancy**	Validate that our edit classes are relevant (i.e., all classes occur in practice).
	Result	All classes occur in practice (91,000 to 22 million occurrences). ✓

From Theory to Practice

RG_1	**Variation Diffs**	Validate completeness of variation diffs.
	Result	All patches with syntactically correct variability annotations can be parsed (99.82%). ✓ $\Rightarrow$ ◯
RG_2	**Classification**	Validate completeness and unambiguity of classification.
	Result	All edits were assigned exactly one class. ✓ $\Rightarrow$ ◯ $\wedge$ ◯◯
RG_3	**Relevancy**	Validate that our edit classes are relevant (i.e., all classes occur in practice).
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RG_4	**Scalability**	Validate that edit classification can be automated and scales.

From Theory to Practice

RG_1	**Variation Diffs**	Validate completeness of variation diffs.
	Result	All patches with syntactically correct variability annotations can be parsed (99.82%). ✓ ⇒ ◯
RG_2	**Classification**	Validate completeness and unambiguity of classification.
	Result	All edits were assigned exactly one class. ✓ ⇒ ◯ ∧ ◯◯
RG_3	**Relevancy**	Validate that our edit classes are relevant (i.e., all classes occur in practice).
	Result	All classes occur in practice (91,000 to 22 million occurrences). ✓
RG_4	**Scalability**	Validate that edit classification can be automated and scales.
	Result	99.89% of commits processed in < 1s with 7ms/commit as median. ✓ ⇒

```
#ifdef A
 foo();
#else
 #ifdef B
 baz();
 #endif
#endif
```

diff

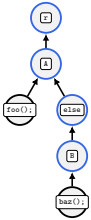
```
 #ifdef A
   foo();
-#else
-  #ifdef B
+  bar();
+#endif
+#if B && (!A || C)
   baz();
-  #endif
 #endif
```

diff

```
#ifdef A
 foo();
 bar();
#endif
#if B && (!A || C)
 baz();
#endif
```

```
#ifdef A
  foo();
#else
  #ifdef B
  baz();
  #endif
#endif
```

parse



diff

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+#endif
+#if B && (!A || C)
    baz();
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```

diff

```
#ifdef A
  foo();
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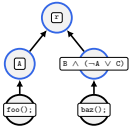
parse



```
#ifdef A
  foo();
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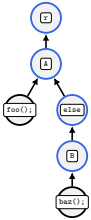
```

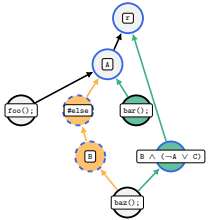
parse



diff

```
#ifdef A
  foo();
-#else
-  #ifdef B
+  bar();
+#endif
+#if B && (!A || C)
  baz();
-  #endif
#endif
```

parse



diff

diff

diff

```
#ifdef A
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#endif
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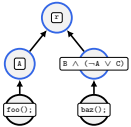
```

parse



```
#ifdef A
  foo();
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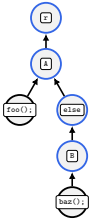
  #endif
#endif
```

parse



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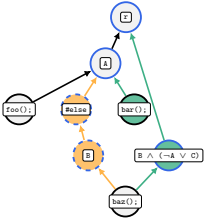
parse



classify

diff

diff

diff

```
#ifdef A
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  bar();
#endif
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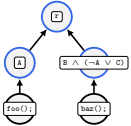
  baz();
#endif
```

parse



```
#ifdef A
  foo();
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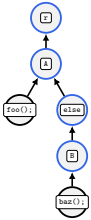
#endif
```

parse



diff

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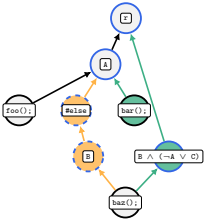
```

parse



diff

diff

diff

```
#ifdef A
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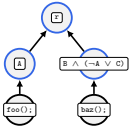
```

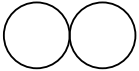
parse



classify

Complete

Unambiguous



Automated

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