Measuring and improving quality of automated program repair

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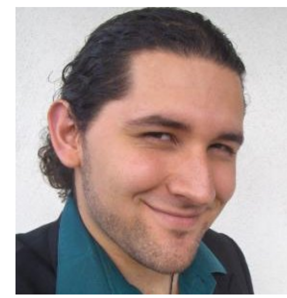
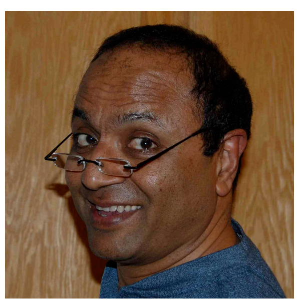


Ted Smith Yalin Ke Manish Motwani Mauricio Soto



Earl Barr Prem Devanbu Claire Le Goues René Just Katie Stolee

Automated Program Repair

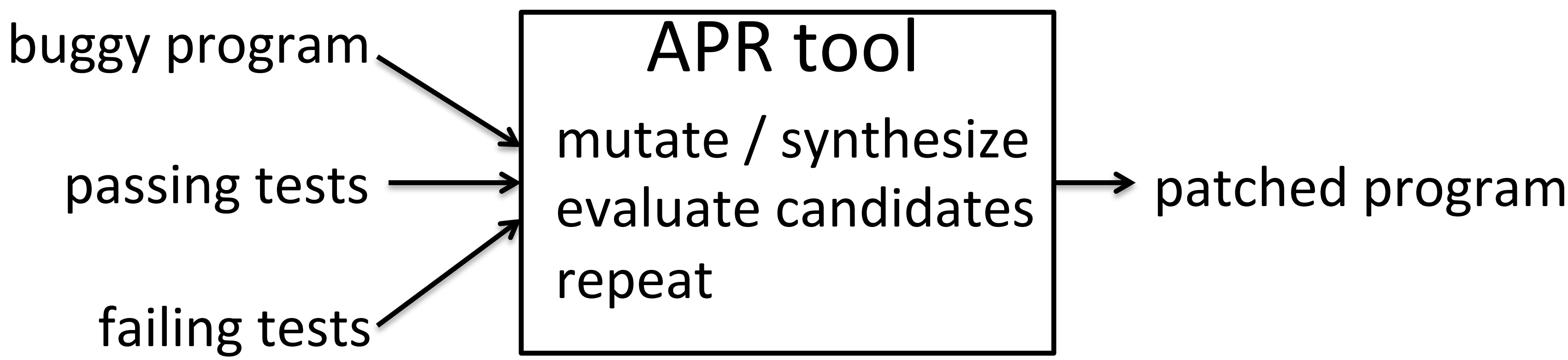
- Given a software system with a bug
  - (typically) a set of passing and a set of failing tests –

  produce a variant of that software system without the bug.

Given a system S that passes tests T_p and fails tests T_f, automatically produce S' that passes T_p and T_f

Exploration-based approaches

basic idea:



the many exploration-based repair tools

ClearView [Perkinds et al. 2009] GenProg [Weimer et al. 2009]

Prophet [Long and Rinard 2016] SPR [Long and Rinard 2015]

TDS [Perelman et al. 2014]

Par [Kim et al. 2013] AE [Weimer et al. 2013]

SemFix [Nguyen et al. 2013] AutoFix-E [Wei et al. 2010]

[Carzaniga et al. 2010] [Carzaniga et al. 2013]

[Jin et al. 2011] Coker and Hafiz et al. 2013]

[Debroy and Wong et al. 2010] [Lin and Ernst et al. 2004]

[Forrest et al. 2009] [Novark et al. 2007] [Demsky et al. 2006]

The automatic program repair story

- Early papers asked:
  - What fraction of bugs can APR fix?
  - How long does it take APR to fix bugs?
  - How much does it cost for APR to fix bugs?
  - Can humans maintain APR fixes?

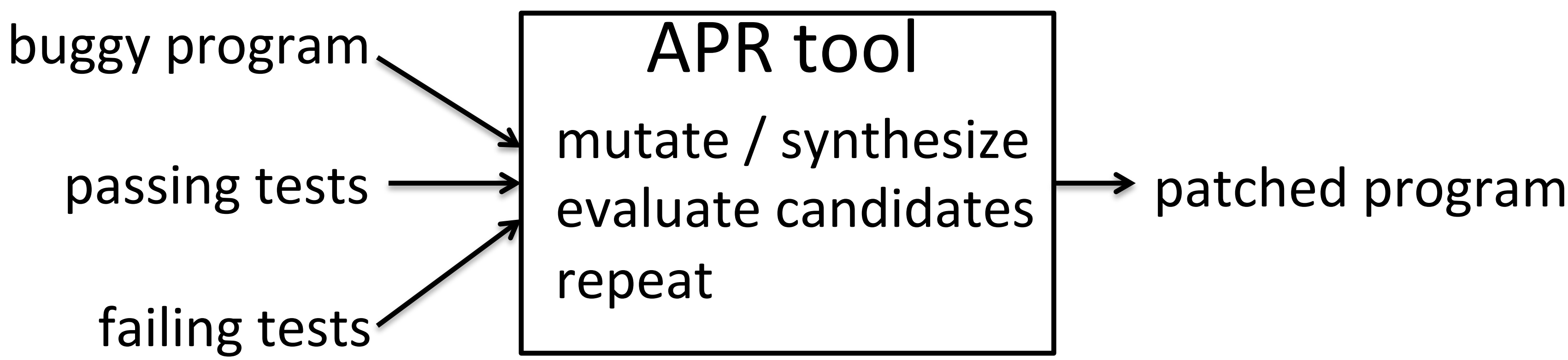
The story was, APR produces a patch that passes all tests

implies

problem solved

Cobra effect

Does exploration-based repair repair?



The patch may break untested or under-tested functionality

How can we know if APR repairs

- Look at the produced patches by hand
  [Qi, Long, Achour, Rinard, ISSTA 2015]
  [Durieux, Martinez, Monperrus, Sommerard, Xuan, 2015]
- Have others look at the produced patches by hand
  [Fry, Landau, Weimer, ISSTA 2012]
  [Kim, Nam, Song, Kim, ICSE 2013]

- Produce patches with test suite T,
  evaluate them on independent test suite T'
  [Brun, Barr, Xiao, Le Goues, Devanbu, 2013]
  [Smith, Barr, Le Goues, Brun, ESEC/FSE 2015]
  - objective
  - repeatable

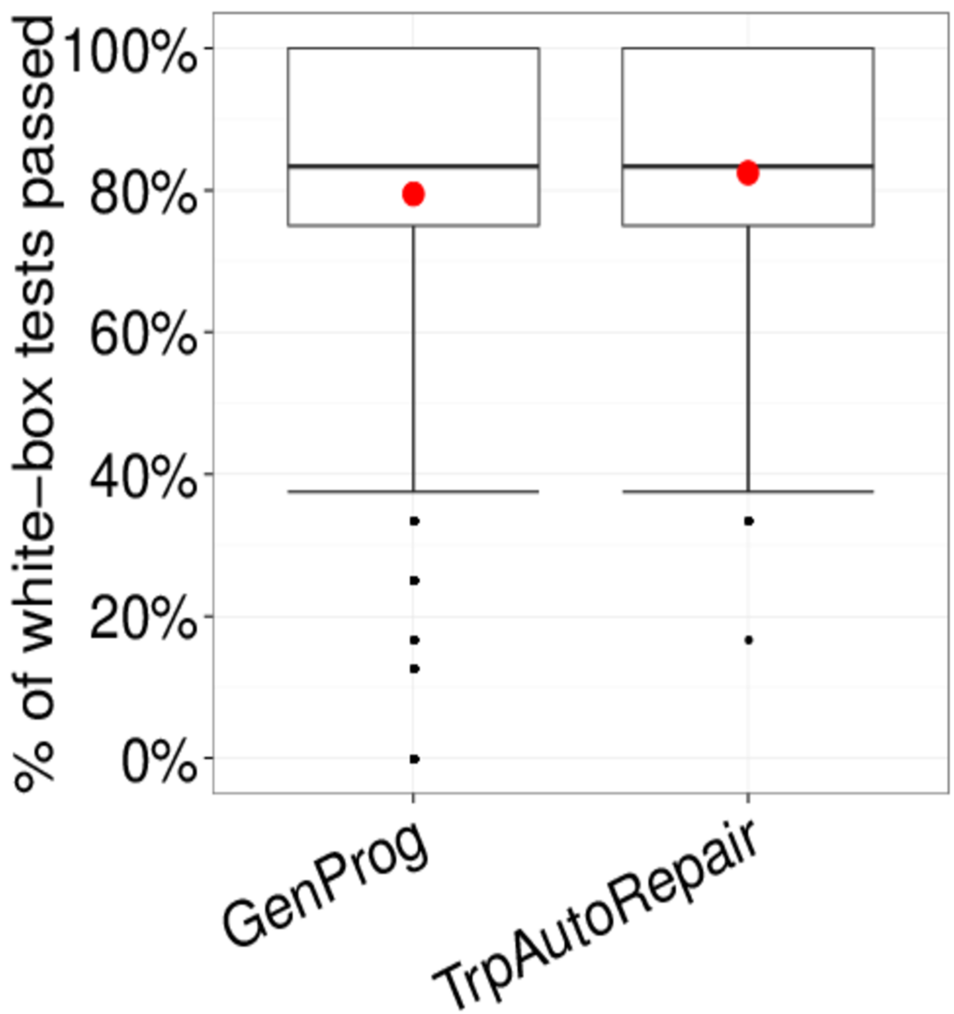
IntroClass Benchmark

Requires a large set of bugs
for programs with 2 independent test suites
and the test suites need to be good

- IntroClass:
  998 bugs in very small, student-written C programs,
  with a KLEE-generated test suite,
  and a human-written test suite.

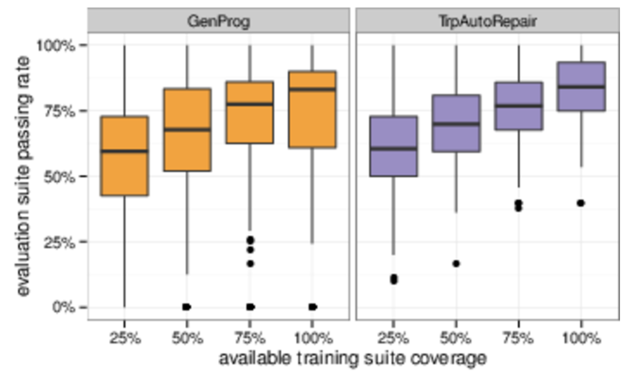
- http://repairbenchmarks.cs.umass.edu, [TSE 2015]

Do GenProg and TrpAutoRepair patches pass kept-out tests?



More GenProg and TrpAutoRepair findings

- The better the test suite coverage, the better the patch



- APR causes harm to high-quality programs, but is helpful for low-quality programs
- Human-written tests lead to better patches
- Student-written patches also break tests.

More answers and details in
"Is the Cure Worse Than the Disease? Overfitting in Automated Program Repair"
by Smith, Barr, Le Goues, Brun, ESEC/FSE 2015

Can we improve the patch quality?

- Recent work:
  - SPR [Long and Rinard, ESEC/FSE 2015]
  - Prophet [Long and Rinard, POPL 2016]
- Both SPR and Prophet produce more correct patches than GenProg, TrpAutoRepair, AE

- My vision: repair at a higher level

SearchRepair: Use existing code

Replace whole code blocks with code from other projects (e.g., GitHub)

Imagine a program with a buggy sort method:

Option 1

Mutate, synthesize, and tweak the sort method until a set of sorting tests pass

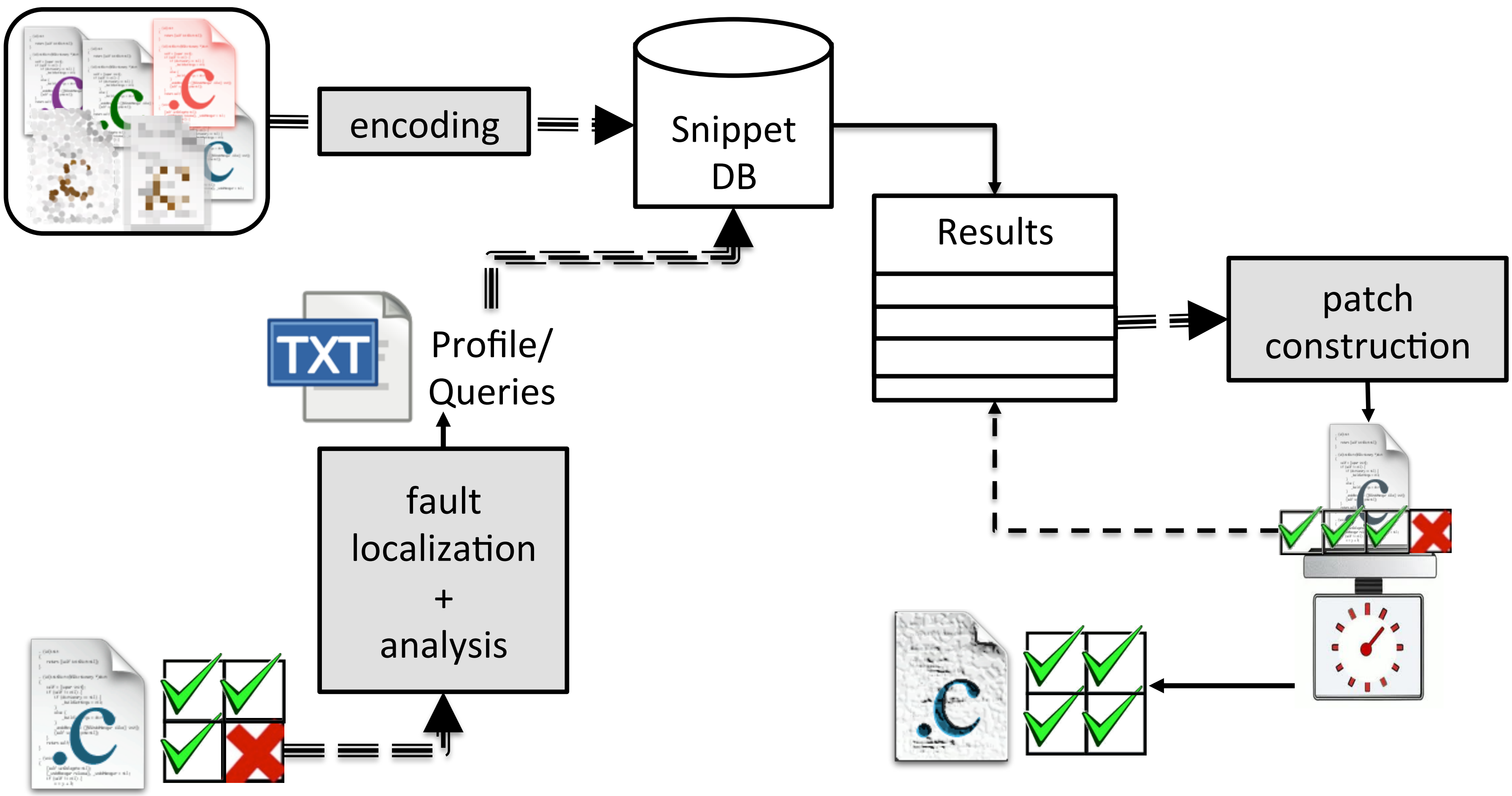
Option 2

Find a method on GitHub that passes the sorting tests

"Repairing Programs with Semantic Code Search" by Ke, Stolee, Le Goues, Brun, ASE 2015

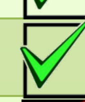
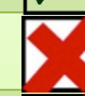
SearchRepair: Use existing code

Replace whole code blocks with code from other projects (e.g., GitHub)



Example: median

```c
int main() {
 int a, b, c, median = 0;
 printf("Please enter 3 numbers separated by spaces >");
 scanf("%d%d%d", &a, &b, &c);
 if ((a<=b && a>=c) || (a>=b && a<=c))
     median = a;
 else if ((b<=a && b>=c) || (b>=a && b<=c))
     median = b;
 else if ((c<=b && a>=c) || (c>=b && a<=c))
     median = c;
 printf("%d is the median", median);
 return 0;
}
```

test	input	test result
t_1	9 9 9	
t_2	0 2 3	
t_3	0 1 0	
t_4	2 0 1	
t_5	2 8 6	

Encoding

Given snippets of code, automatically compute the SMT constraints between snippet inputs and outputs. Store in DB.

```
if((x <= y && x >= z) || (x >= y && x <=z))
    m = x;
else if((y <=  x && y >= z) || (y >= x && y <= z))
    m = y;
else
    m = z;
```

```
vars:  LOCAL(int x, int y, int z, int m)
  p1:  ASSUME[(x <= y && x >= z)|| (x >= y && x <=z)]
       STMT[m = x]
  p2:  ASSUME[not((x <= y && x >= z)|| (x >= y && x <=z))
            && ((y <= x && y >= z)|| (y >= x && y <= z))]
       STMT[m = y]
  p3:  ASSUME[not((x <= y && x >= z)|| (x >= y && x <=z))
            && not((y <= x && y >= z)|| (y >= x && y <= z))]
       STMT[m = z]
```

Fault localization

Identify the code lines that execute more often on failing tests, the elevate these lines to block level.

```c
int main() {
 int a, b, c, median = 0;
 printf("Please enter 3 numbers separated by spaces >");
 scanf("%d%d%d", &a, &b, &c);
 if ((a<=b && a>=c) || (a>=b && a<=c))
    median = a;
 else if ((b<=a && b>=c) || (b>=a && b<=c))
    median = b;
 else if ((c<=b && a>=c) || (c>=b && a<=c))
    median = c;
 printf("%d is the median", median);
 return 0;
}
```

Semantic search and context

Identify input-output behavior on passing tests, and use SMT solver to find satisfying snippets in DB (potential patches).

```c
int main() {
 int a, b, c, median = 0;
 printf("Please enter 3 numbers separated by spaces >");
 scanf("%d%d%d", &a, &b, &c);
 if ((a<=b && a>=c) || (a>=b && a<=c))
    median = a;
 else if ((b<=a && b>=c) || (b>=a && b<=c))
    median = b;
 else if ((c<=b && a>=c) || (c>=b && a<=c))
    median = c;
 printf("%d is the median", median);
 return 0;
}
```

```c
if((x <= y && x >= z) || (x >= y && x <=z))
    m = x;
else if((y <=  x && y >= z) || (y >= x && y <= z))
    m = y;
else
    m = z;
```

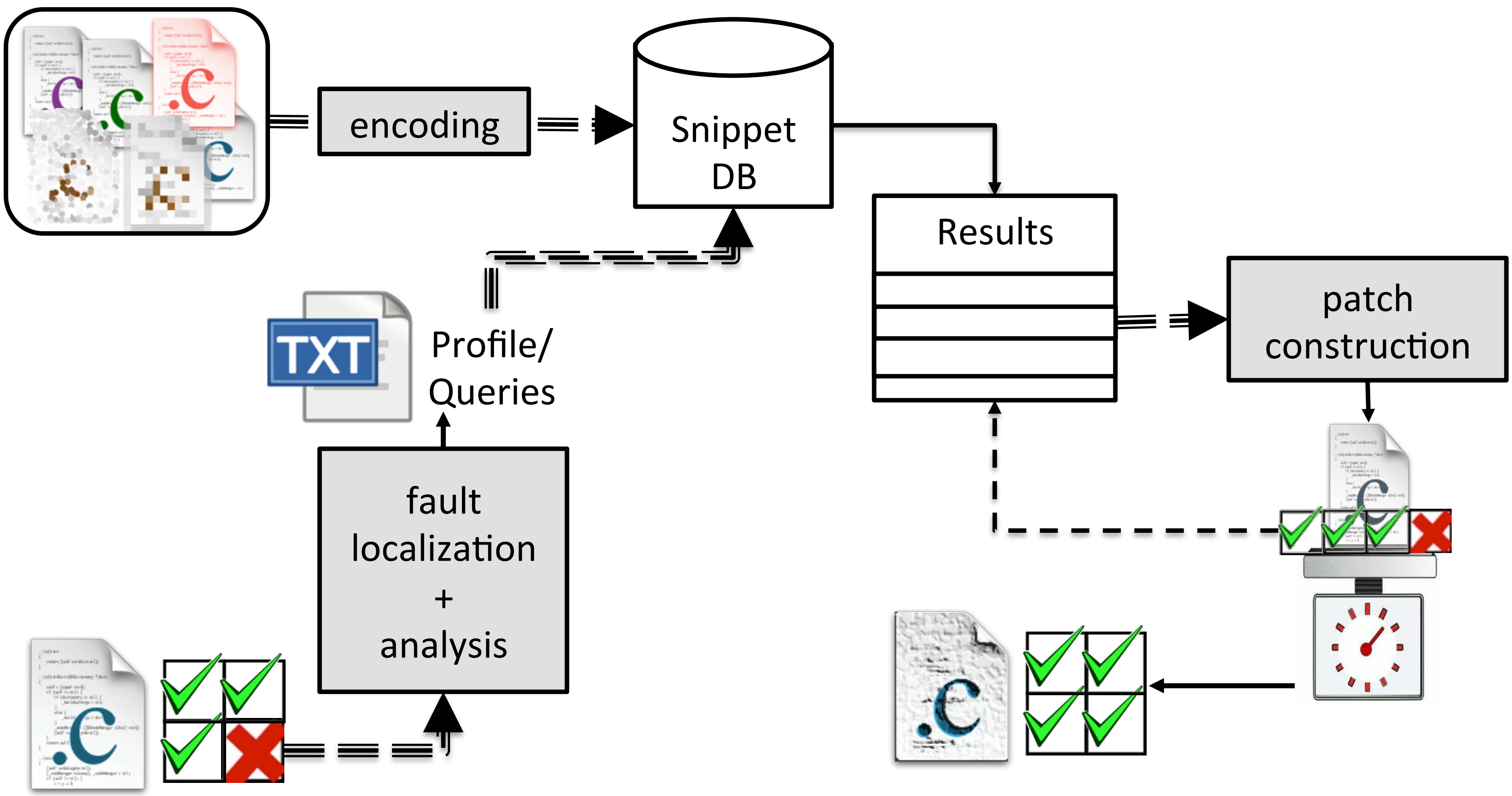
Barr, Harman, Jia, Marginean, Petke, ISSTA 2015 could enable larger-scale transplantation

Validate potential patches

Rerun tests to select patches that repair the bug.

SearchRepair: Use existing code

- Replace whole code blocks with code from other projects (e.g., GitHub)



SearchRepair vs. Exploration

% of kept-out tests patches pass

SearchRepair	GenProg	TRPAutoRepair	AE
97.2%	68.7%	72.1%	64.2%

"Repairing Programs with Semantic Code Search" by Ke, Stolee, Le Goues, Brun, ASE 2015

Contributions

- Repeatable, automated, objective methodology for evaluating automated repair quality
  - including the IntroClass dataset
- SearchRepair: semantic-search-based repair
- A small-scale prototype of SearchRepair, evaluated on IntroClass
  - greatly improves repair quality over GenProg, TrpAutoRepair, and AE