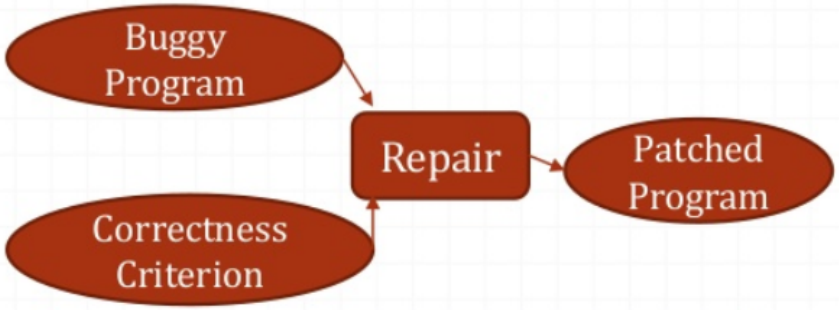
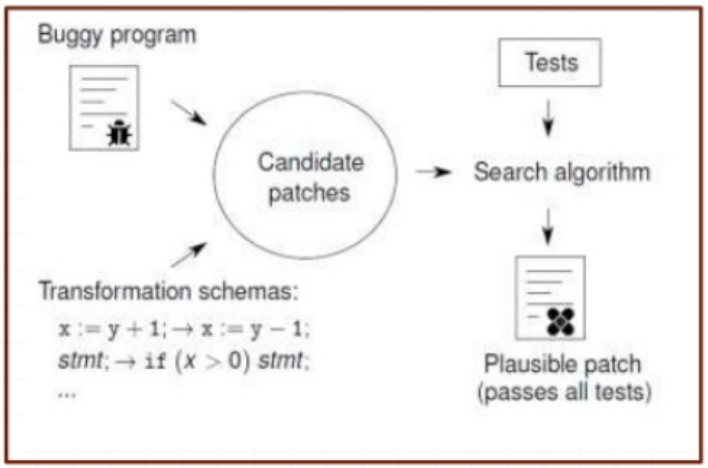
Program Repair

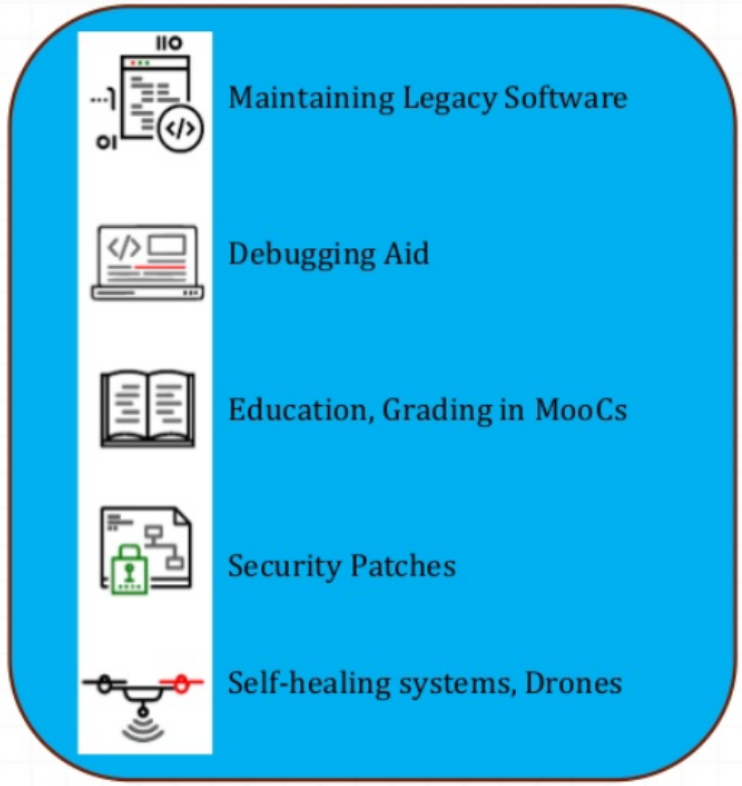
selected slides from Prof Abhik Roychoudhury's keynote talk

March 22, 2021

Repair - Why?







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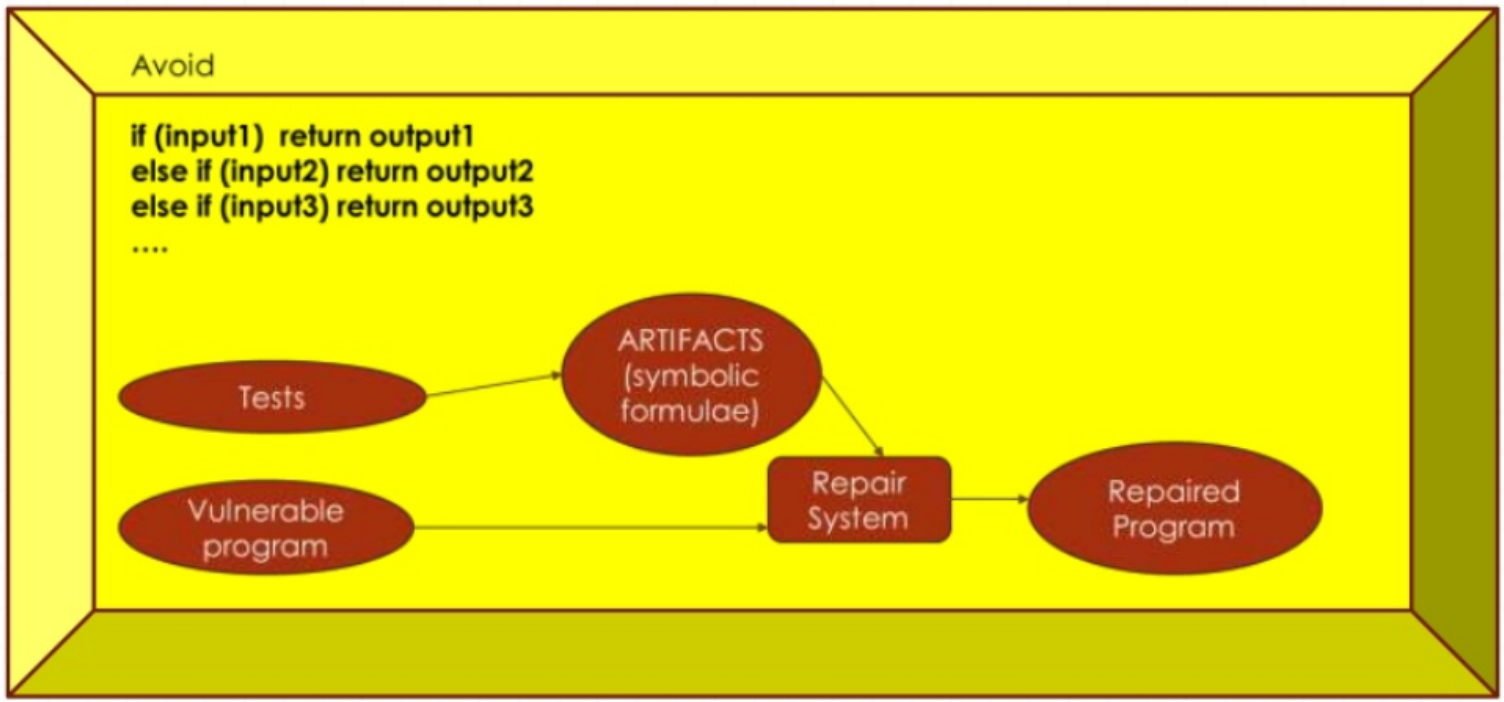
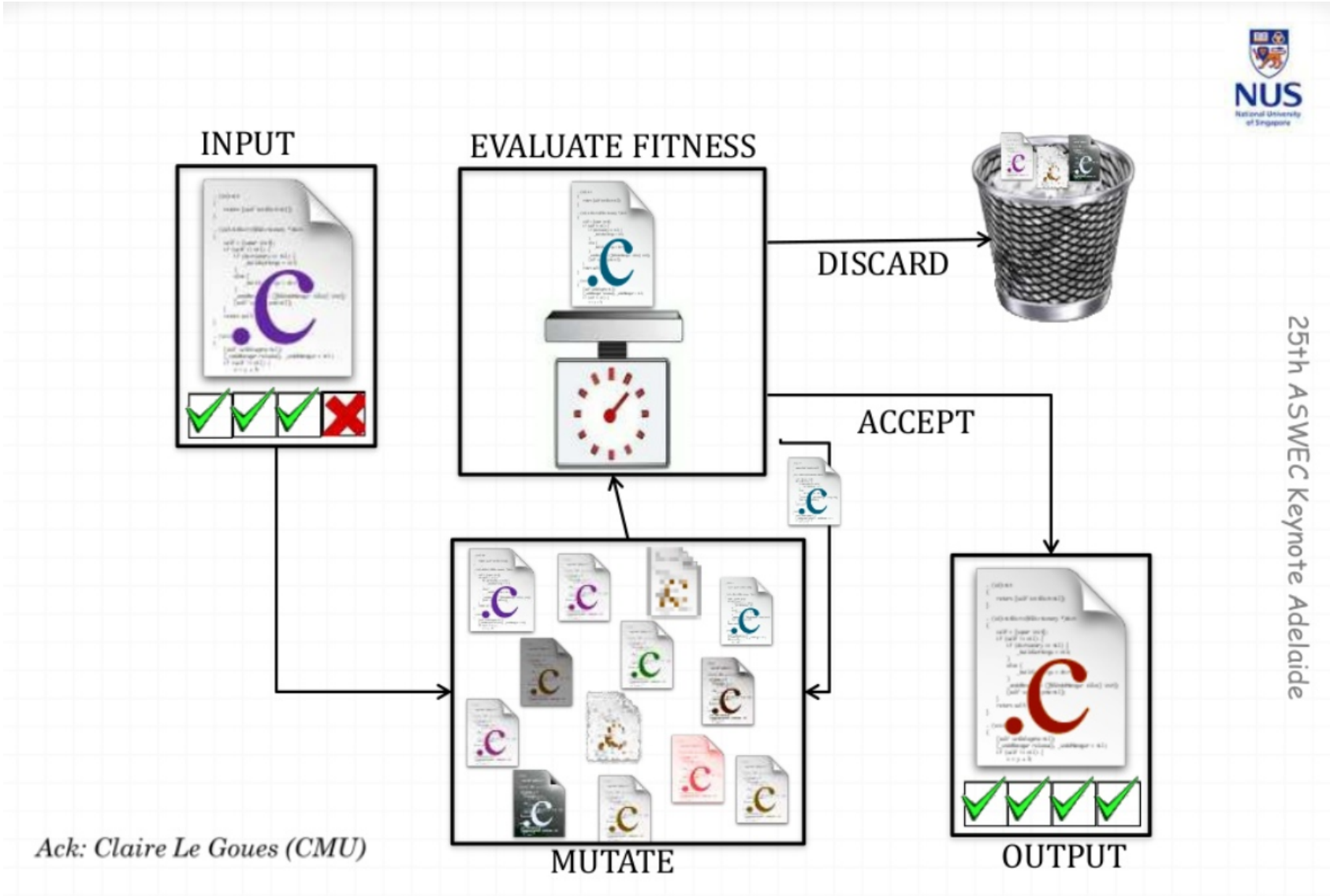
Troubles with repair

- Weak description of intended behavior / *correctness criterion* e.g. tests
  - Possibility to use "Bugs as deviant behavior" philosophy
- Weak applicability of repair techniques e.g. only overflow errors
- *Large search space* of candidate patches for general-purpose repair tools.
- Patch suggestions and *Interactive Repair*




INPUT
EVALUATE FITNESS
DISCARD
ACCEPT
MUTATE
OUTPUT
Ack: Claire Le Goues (CMU)
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```
1 int triangle(int a, int b, int c){
2     if (a <= 0 || b <= 0 || c <= 0)
3         return INVALID;
4     if (a == b && b == c)
5         return EQUILATERAL;
6     if (a == b || b != c) // bug!
7         return ISOSCELES;
8 return SCALENE;
9 }
```

Test id	a	b	c	oracle	Pass
1	-1	-1	-1	INVALID	pass
2	1	1	1	EQUILATERAL	pass
3	2	2	3	ISOSCELES	pass
4	2	3	2	ISOSCELES	fail
5	3	2	2	ISOSCELES	fail
6	2	3	4	SCALENES	fail

Correct fix
(a == b || b == c || a== c)

Traverse all *mutations* of line 6, and check

Hard to generate correct fix since a==c never appears elsewhere in the program.

OR

Generate the constraint

$f(2,2,3) \wedge f(2,3,2) \wedge f(3,2,2) \wedge \neg f(2,3,4)$

and get the solution

f(a,b,c) = `(a == b || b == c || a== c)`

NUS National University of Singapore

Comparison

Syntactic Program Repair

Syntax-based Schematic
for e in Search-space{
    Validate e against Tests
}

1. Where to fix, which line?
2. Generate patches in the candidate line
3. Validate the candidate patches against correctness criterion.

Semantic Program Repair

Semantics-based Schematic
for t in Tests {
    generate repair constraint Ψ_t
}
Synthesize e from $\wedge_t \Psi_t$

1. Where to fix, which line(s)?
2. What values should be returned by those lines, e.g. <inp ==1, ret== 0>
3. What are the expressions which will return such values?

The Heartbleed Bug is a serious vulnerability in the popular OpenSSL cryptographic software library. This weakness allows stealing the information protected, under normal conditions, by the SSL/TLS encryption used to secure the Internet. SSL/TLS provides communication security and privacy over the Internet for applications such as web, email, instant messaging (IM) and some virtual private networks (VPNs).

--- Source: heartbleed.com

```
1   if ( hbtype == TLS1_HB_REQUEST) {
2       ...
3       memcpy (bp , pl , payload ) ;
4       ...
5   }
```

(a) The buggy part of the Heartbleed-vulnerable OpenSSL

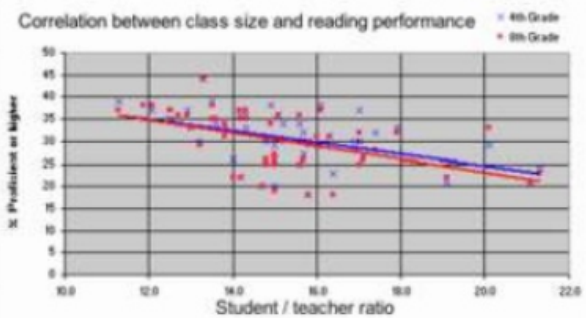
```
1   if ( hbtype == TLS1_HB_REQUEST
2       && payload + 18 < s->s3->rrec.length) {
3       ...
4   }
```

(b) A fix generated automatically

```
1   if(1 + 2 + payload + 16 > s->s3->rrec.length)
2       return 0;
3   ...
4   if ( hbtype == TLS1_HB_REQUEST) {
5       ...
6   }
7   else if ( hbtype == TLS1_HB_RESPONSE) {
8       ...
9   }
10  return 0;
```

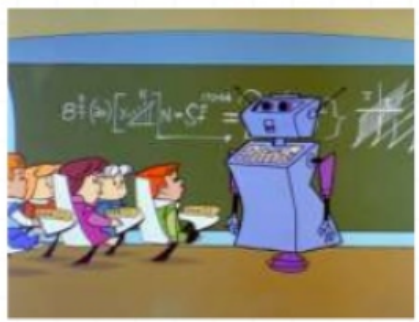
(c) The developer-provided repair

Application in education

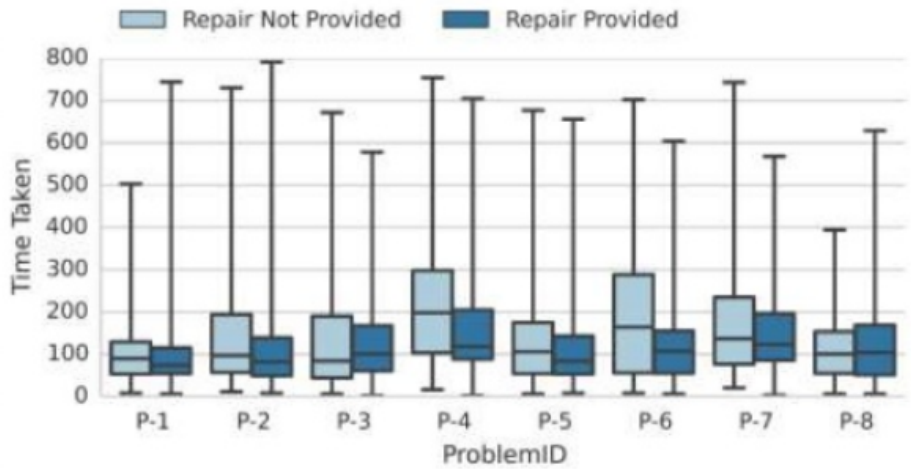


Use program repair in intelligent tutoring systems to give the students' individual attention.

Detailed Study in IIT-Kanpur, India by Prof. Amey Karkare and team (FSE17)



Application in Education



43 buggy student submissions from dataset
Across 8 unique problems

37 TA graders volunteered for study
Each TA gets all 43 submissions to grade
With repair hints for half the submissions

Example

```
1  int is_upward( int inhibit, int up_sep, int down_sep){
2        int bias;
3        if (inhibit)
4            bias = down_sep; //   bias= up_sep + 100
5        else  bias = up_sep ;
6        if (bias > down_sep)
7             return 1;
8        else return 0;
9  }
```

inhibit	up_sep	down_sep	Observed output	Expected Output	Result
1	0	100	0	0	pass
1	***11***	***110***	***0***	***1***	***fail***
0	100	50	1	1	pass
1	***-20***	***60***	***0***	***1***	***fail***
0	0	10	0	0	pass

What it should have been

Inhibit == 1	up_sep == 11	down_sep == 110

```
1  int is_upward( int inhibit, int up_sep, int
   down_sep){
2        int bias;
3        if (inhibit)
4            bias = f(inhibit, up_sep, down_sep)
5        else  bias = up_sep ;
6        if (bias > down_sep)
7            return 1;
8        else return 0;
9  }
```

Symbolic Execution

f(1,11,110) > 110

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Fix the suspect

- Accumulated constraints
  - $f(1,11, 110) > 110 \wedge$
  - $f(1,0,100) \leq 100 \wedge$
  - ...
- Find a f satisfying this constraint
  - By fixing the set of operators appearing in f
- Candidate methods
  - Search over the space of expressions
  - Program synthesis with fixed set of operators
    - Can also be achieved by second-order constraint solving
- Generated fix
  - `f(inhibit,up_sep,down_sep) = up_sep + 100`

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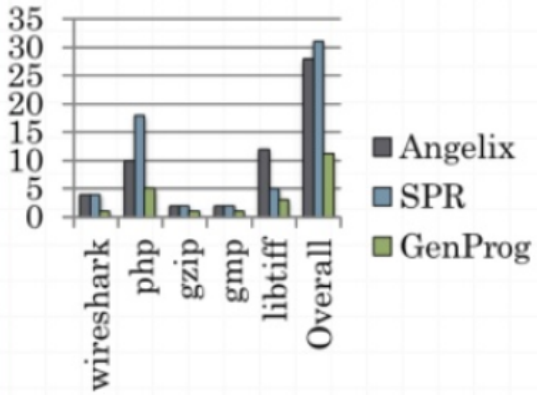
(Sample) Results

Subject	LoC
wireshark	2814K
php	1046K
gzip	491K
gmp	145K
libtiff	77K

Defect	Fixed Expressions
Libtiff-4a24508-cc79c2b	2
Libtiff-829d8c4-036d7bb	2
CoreUtils-00743a1f-ec48bead	3
CoreUtils-1dd8a331-d461bfd2	2
CoreUtils-c5ccf29b-a04ddb8d	3



	#Fixes	Del	Del, Per
Angelix	28	5	18%
SPR	31	13	42%

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SemGraft Results

GNU Coreutils as reference

Program	Commit	Bug	Angelix	SemGraft
sed	c35545a	Handle empty match	Correct	Correct
seq	f7d1c59	Wrong output	Correct	Correct
sed	7666fa1	Wrong output	Incorrect	Correct
sort	d1ed3e6	Wrong output	Incorrect	Correct
seq	d86d20b	Don't accepts 0	Incorrect	Correct
sed	3a9365e	Handle s///	Incorrect	Correct

Linux Busybox as reference

Program	Commit	Bug	Angelix	SemGraft
mkdir	f7d1c59	Segmentation fault	Incorrect	Correct
mkfifo	cdb1682	Segmentation fault	Incorrect	Correct
mknod	cdb1682	Segmentation fault	Incorrect	Correct
copy	f3653f0	Failed to copy a file	Correct	Correct
md5sum	739cf4e	Segmentation fault	Correct	Correct
cut	6f374d7	Wrong output	Incorrect	Correct