Adopting Razor for Post-deployment Software Debloating

Chenxiong Qian, Kevin Koo, Hong Hu,
Taesoo Kim, Wenke Lee

CREATING THE NEXT®

Functionalities Wanted

Functionalities that Come with Installation

Functionalities that Come with Installation

Well-investigated

Functionalities that Come with Installation

Well-investigated

Unknown

Functionalities that Come with Installation

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Unknown

Bloated Code

Bloated Code Increases an Attack Surface

- TLS heartbeat extension.
- Not used by most users.
- Enabled by default.

Software Debloating

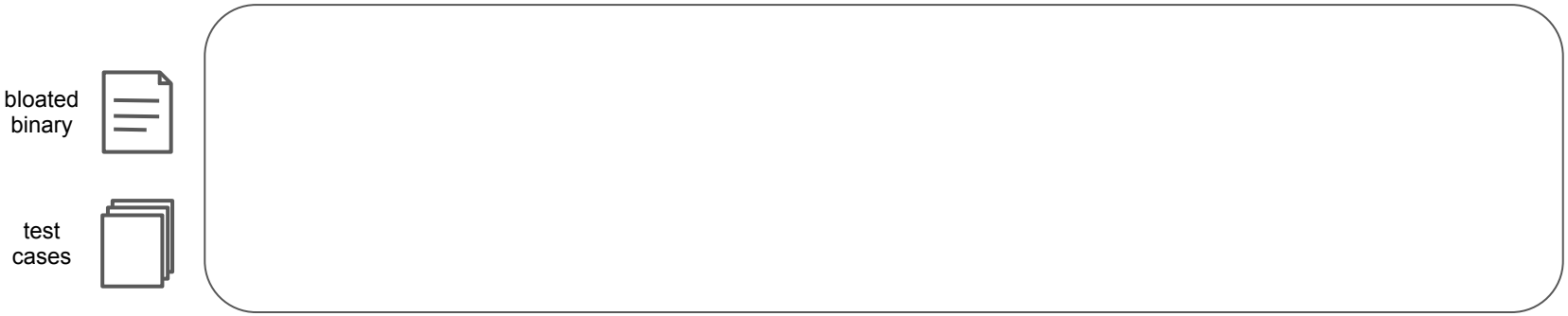
- Most existing software debloating systems have the following limitations:
  - Require source code.
    - Source code is not always accessible to users.
    - It’s challenging and time-consuming to recompile source code.
  - Assume test cases are complete.
    - This assumption mostly fails in real world.
    - Causes over-debloating problem.

Razor

➢ Performs code reduction for deployed **binaries**.

➢ Uses **heuristics** to infer related code for given test cases.

Overview



Overview


Tracer
bloated binary
test cases
Dynamorio
Intel PIN
Intel PT
Razor

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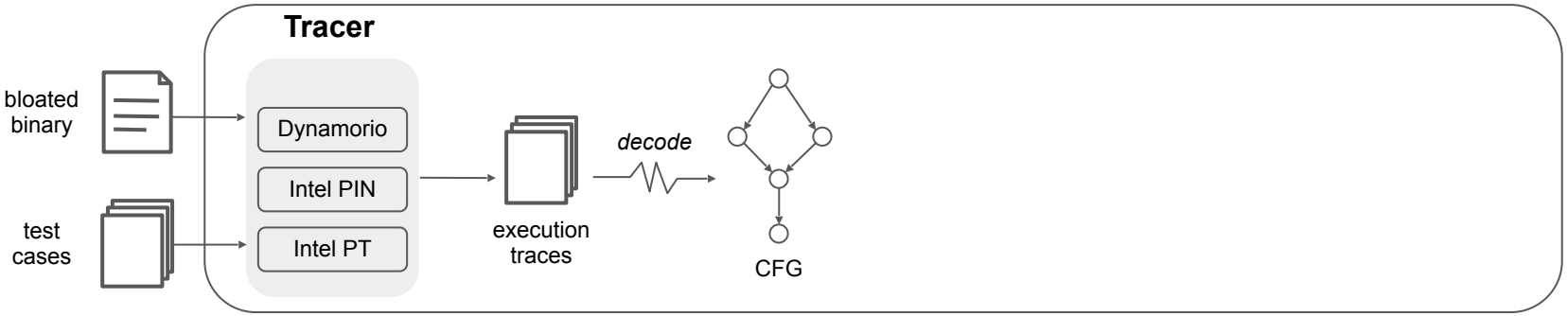
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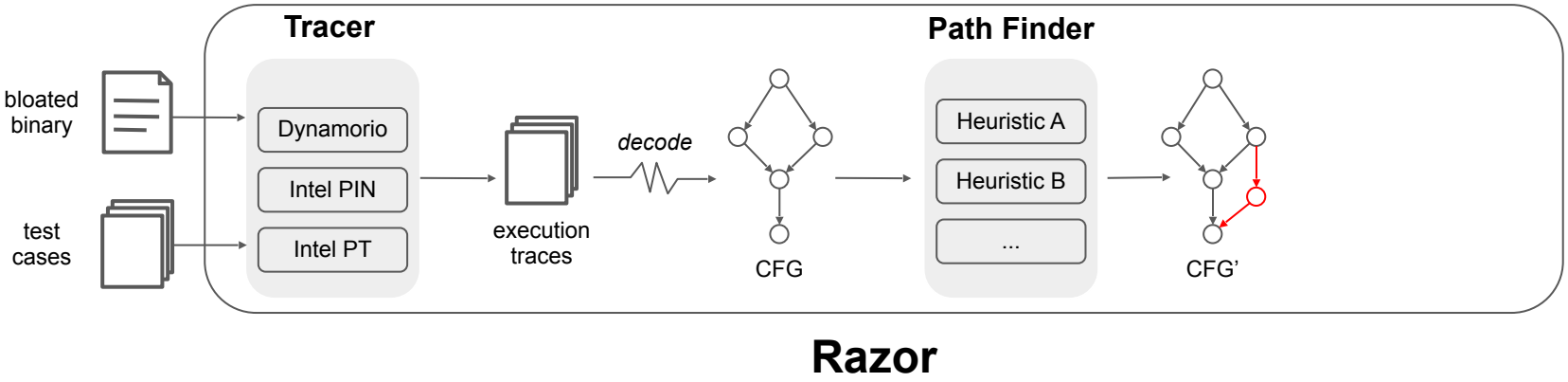
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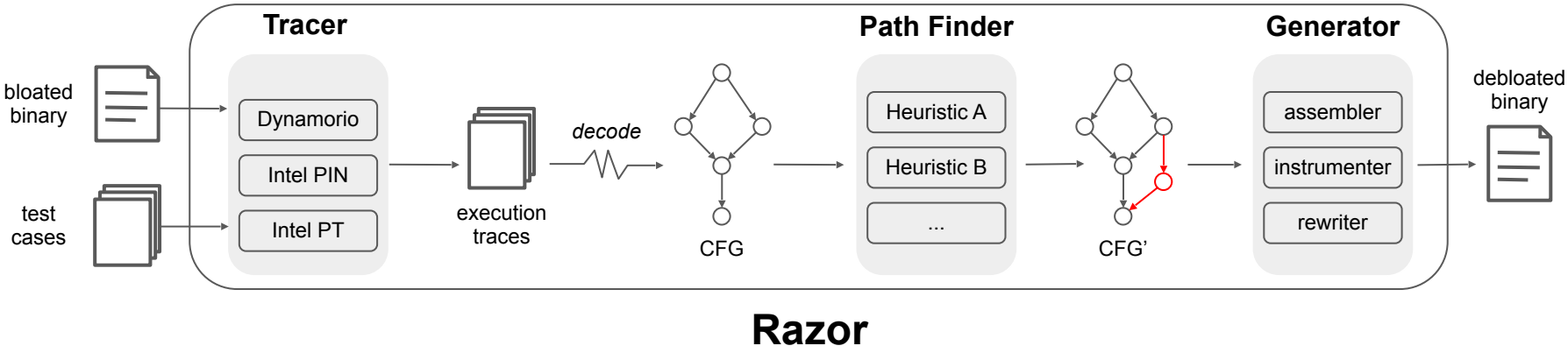
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Generator
assembler
instrumenter
rewriter
debloated binary
Razor

Tracer

- Multiple tracers
  - Software-based tracers (Dynamorio, Intel PIN)
    - Complete trace
    - Significant overhead
  - Hardware-based tracer (Intel PT)
    - Small overhead
    - Incomplete trace

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- The collected trace contains three parts:

Executed Blocks
[0x4005c0, 0x4005f2]
[0x400596, 0x4005ae]
...

Conditional Branches
[0x4004e3: true]
[0x4004ee: false]
[0x400614: true, false]
...

Indirect Calls/Jumps
[0x400677, 0x4005e6#18, 0x4005f6#6
...

Path Finder

- Four Heuristics
  - zCode (zero code)
  - zCall (zero call)
  - zLib (zero library call)
  - zFunc (zero functionality)

Heuristic **zCode**

- Find a path ***p*** not in the executed CFG, add ***p*** if all code on ***p*** is executed.

```
1 char *input = read_input();
2 if (everything_is_ok(input)) {
3     //do the job
4 }
5 return;
6
```

The traces only cover the “true” branch.

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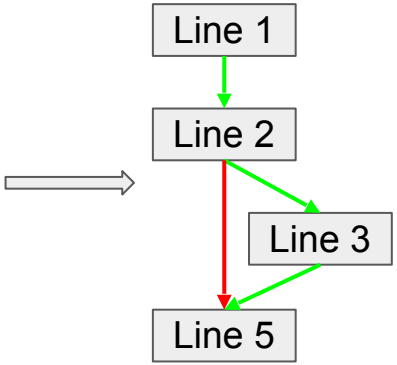

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Line 2 → Line 5
is not allowed.

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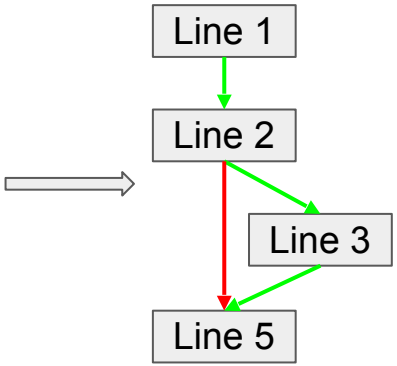

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The path (*Line2 → Line 5*): **all code is executed.**

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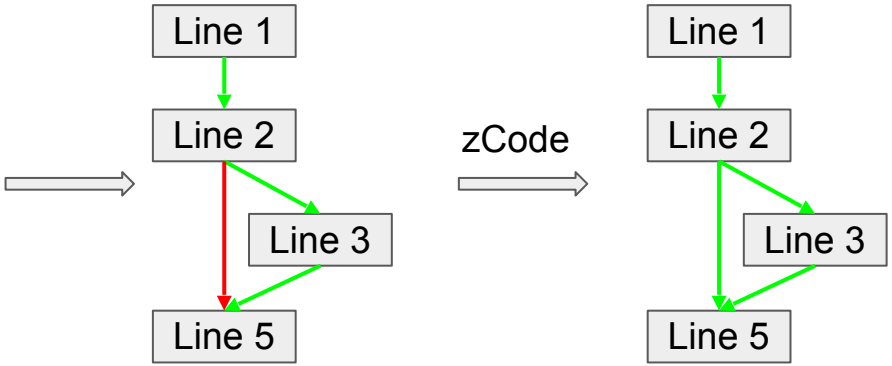

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The path (*Line2 → Line 5*): **all code is executed.**

Heuristic **zCall**

- Find a path ***p*** not in the executed CFG, add ***p*** if there are no call instructions on ***p***.

```
 1 int a = read_a();
 2 int b = read_b();
 3 unsigned int abs = 0;
 4 if (a > b) {
 5     abs = a - b;
 6 } else {
 7     abs = b - a;
 8 }
 9 return abs;
10
```

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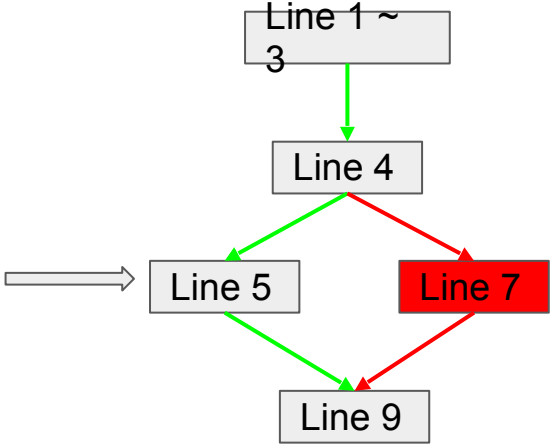

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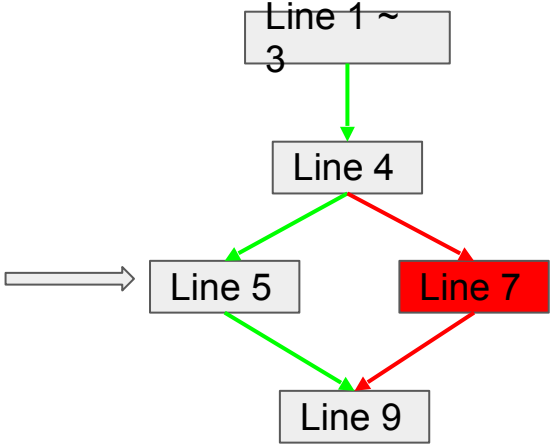

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Line 7 is not executed.

The path (*Line 4* → *Line 7* → *Line 9*): *Line 7* is not executed, but **it does not call functions.**

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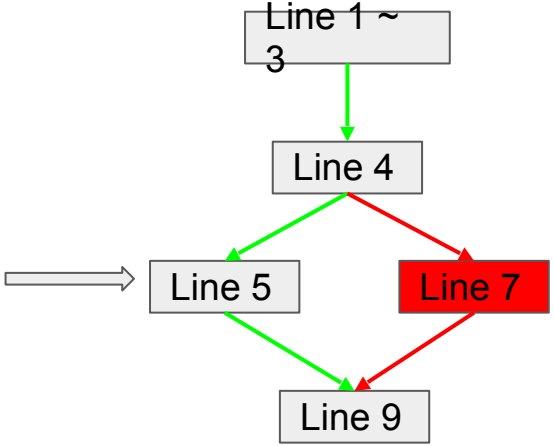

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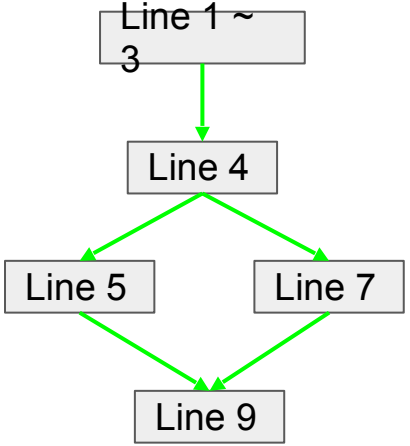

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Line 4 → *Line 7* → *Line 9* is added.

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Heuristic **zLib**

- Find a path ***p*** not in the executed CFG, add ***p*** if ***p*** does not call non-executed library functions.

```
1 int a = read_a();
2 int b = read_b();
3 if (a > b) {
4   printf("a > b\n");
5 } else {
6   printf("a <= b\n");
7 }
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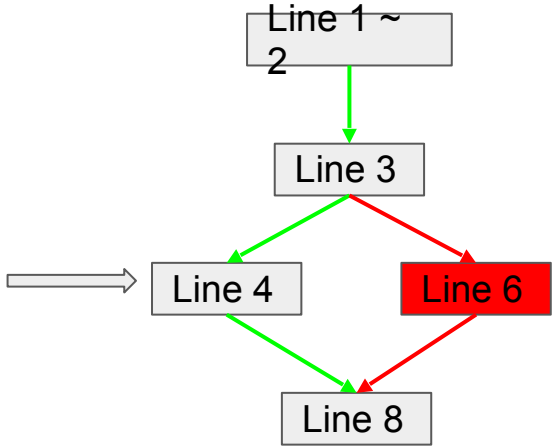

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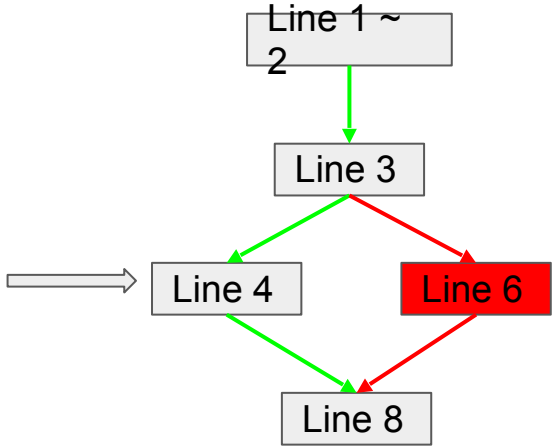

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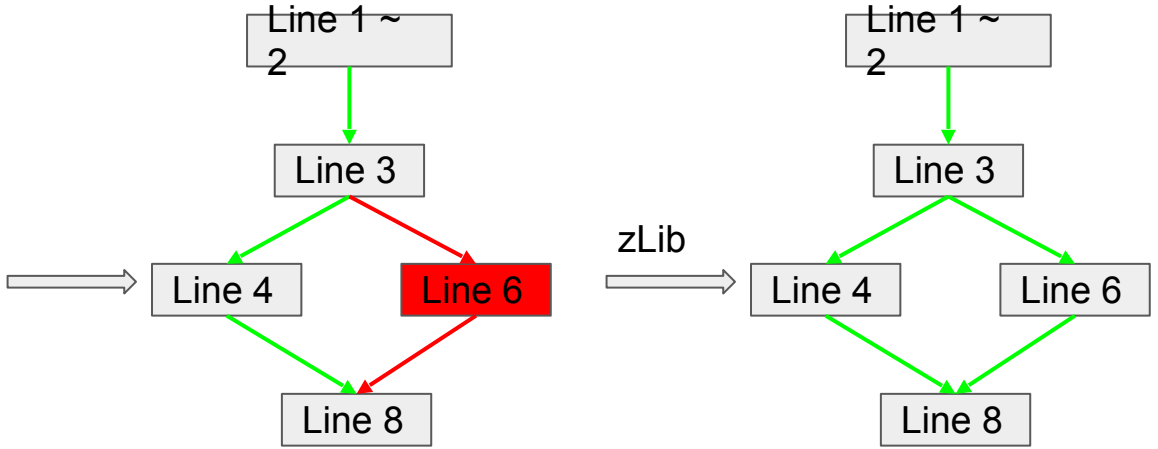

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Heuristic **zFunc**

- ➢ Find a path ***p*** not in the executed CFG, add ***p*** if ***p*** does not call non-executed library functions that share different functionalities.

```
1 int a = read_a();
2 int b = read_b();
3 if (a > b) {
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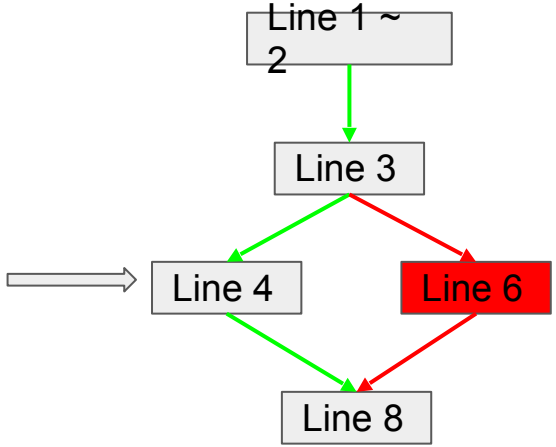

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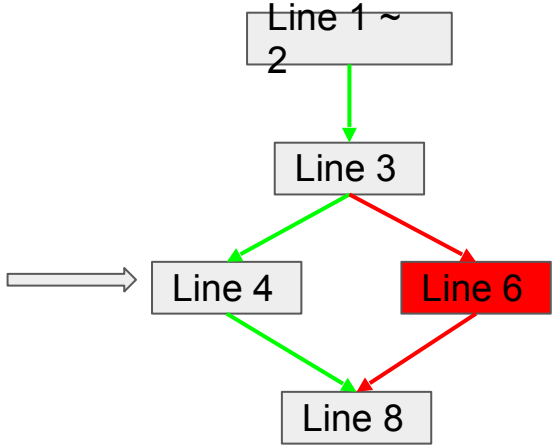

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The path (*Line 3* → *Line 6* → *Line 8*): *Line 6* is not executed and it calls “fprintf”, which is not executed, but: **(1) “printf” is executed; (2) “fprintf” shares the similar functionality with “printf”.**

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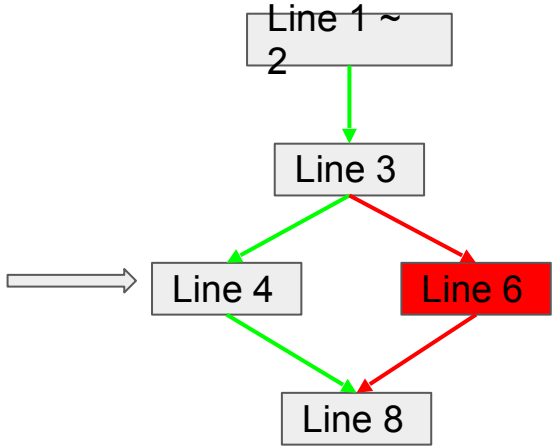

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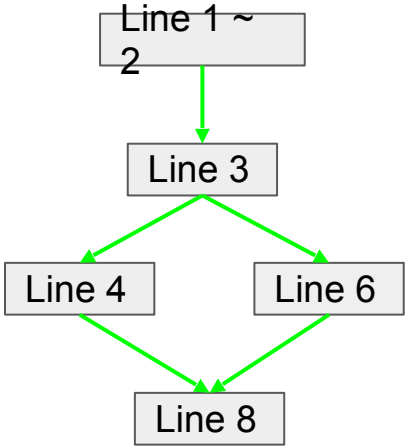

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Generator

- **Assembler**
  - **Disassembles the binary based on the expanded CFG.**
  - **Symbolizes basic blocks.**
- Instrumenter
  - Concretizes targets of indirect calls/jumps.
  - Fixes callback function pointers.
  - Enforce allowed control-flows.
- Rewriter
  - Compiles the instrumented assembly code to an object file.
  - Copies the code section into original binary.

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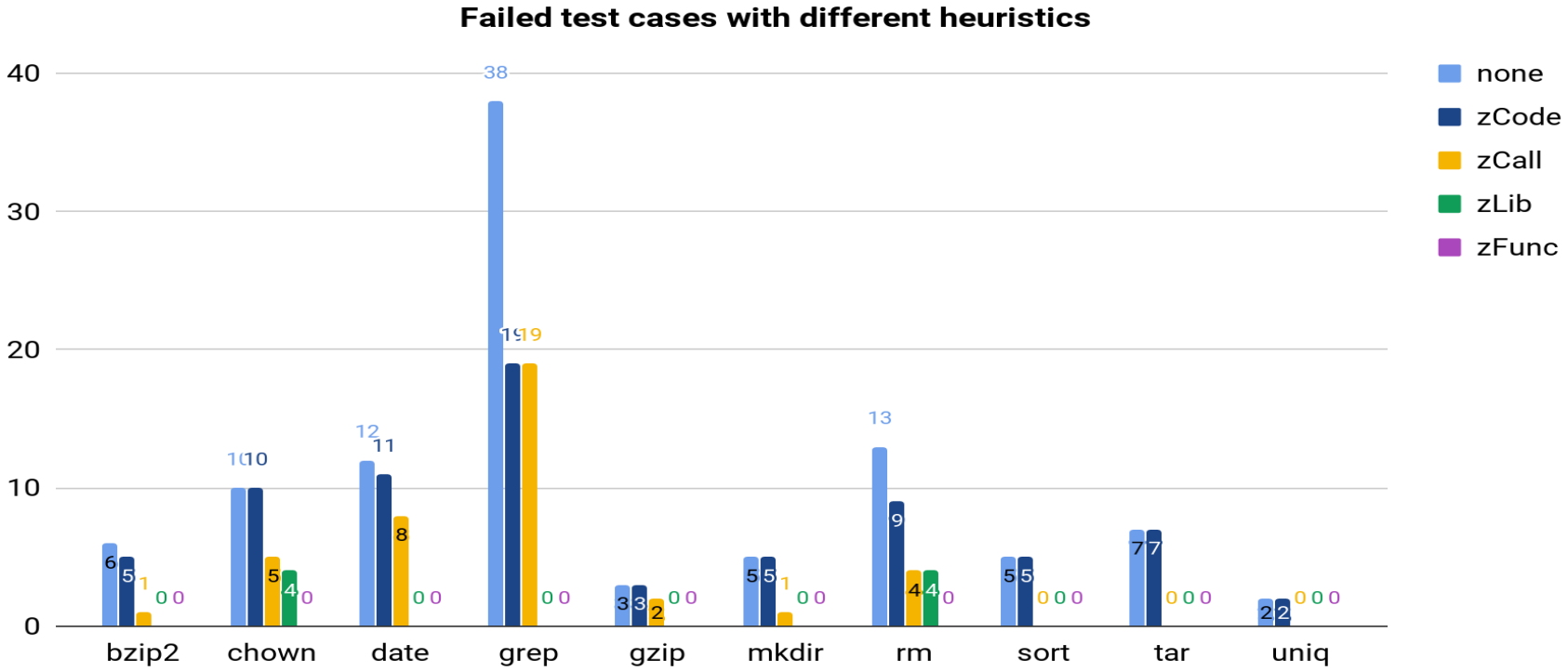
Effectiveness of Heuristics

- Run the debloated binaries on the different test cases.



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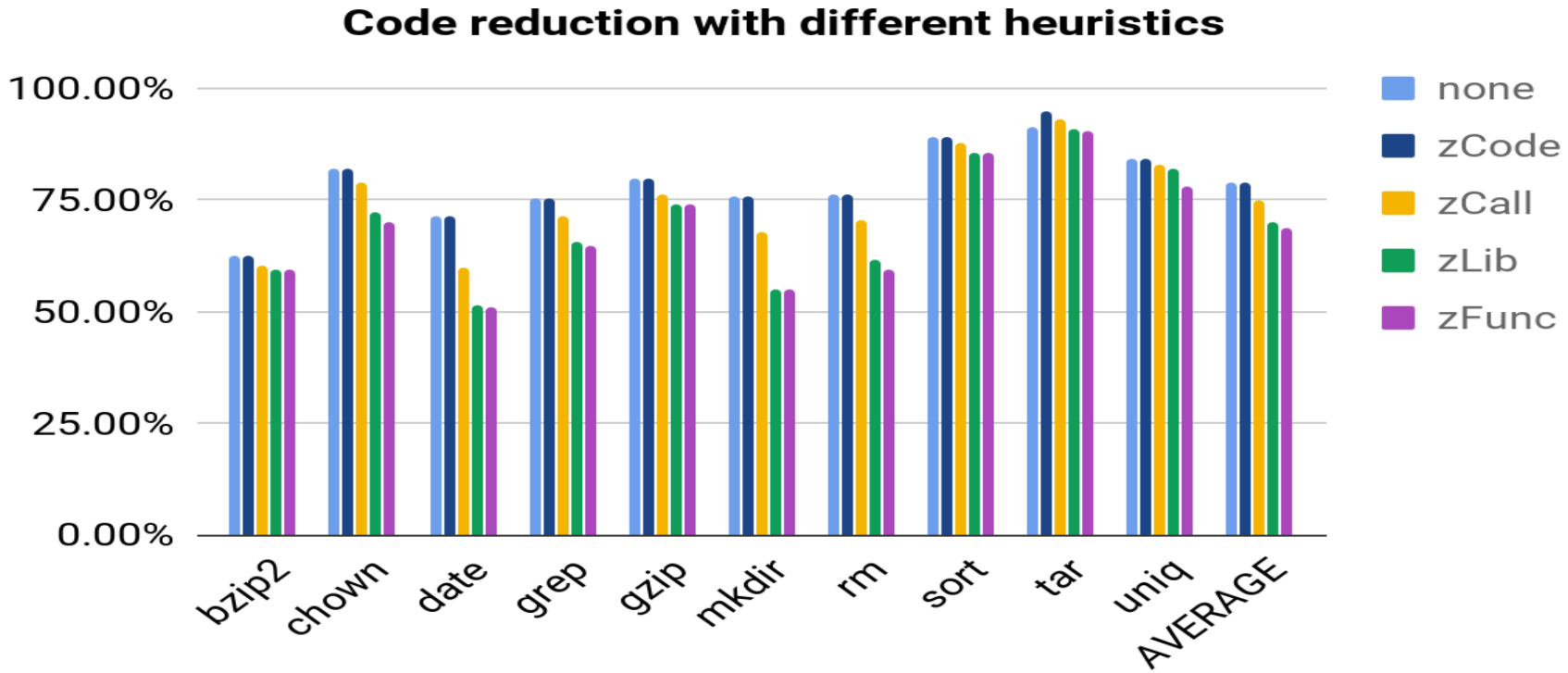


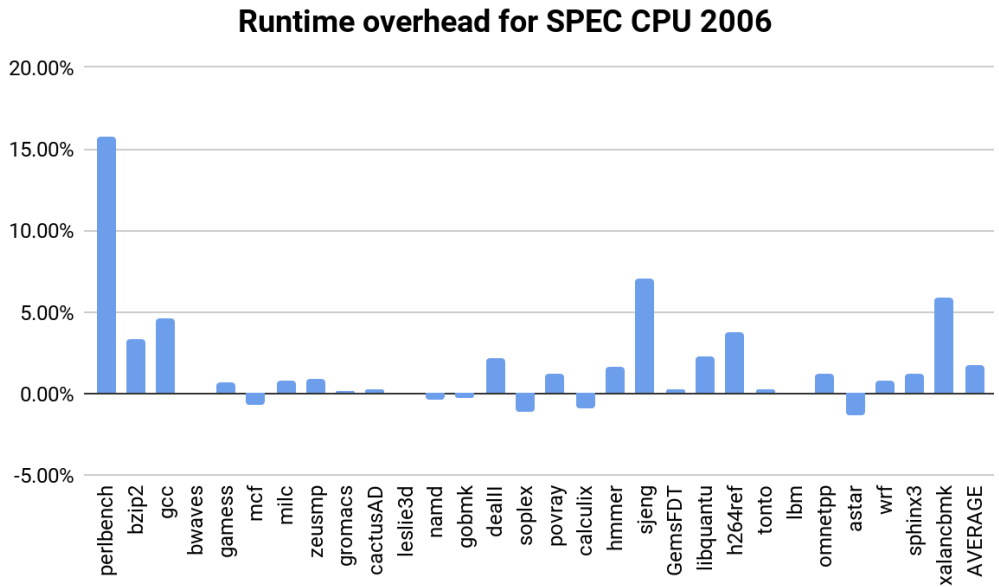
Security Benefits

Program	CVE	Orig	Chisel	Razor
bzip2	CVE-2010-0405	✔		
	CVE-2008-1372	✘	✔	
	CVE-2005-1260	✘	✔	
chown	CVE-2017-18018*	✔	✘	✘
date	CVE-2014-9471*	✔	✘	✔
grep	CVE-2015-1345*	✔	✘	✘
	CVE-2012-5667	✘	✔	
gzip	CVE-2005-1228*	✔	✘	✘
	CVE-2009-2624	✔		
	CVE-2010-0001	✔	✘	✘
mkdir	CVE-2005-1039*	✔		
rm	CVE-2015-1865*	✔		
tar	CVE-2016-6321*	✔	✘	✔

✔ binary is vulnerable to the CVE.
✘ binary is not vulnerable to the CVE.
* CVEs with * are evaluated by

Runtime Overhead

- On average, Razor introduces a 1.7% slowdown.
  - 15.8% overhead for *perlbench*



Real-world Software Debloating

- Firefox
  - Load Top 50 Alexa websites.
  - Randomly pick 25 websites for debloating, and use the other 25 websites for testing.
- FoxitReader
  - Open and scroll 55 different PDF files.
  - Randomly pick 15 files for debloating, and use the other 40 files for testing.

Heuristic	Firefox		FoxitReader	
	crash-sites	code-reduction	crash-PDFs	code-reduction
none	13	67.6%	39	89.8%
zCode	13	68.0%	10	89.9%
zCall	2	63.1%	5	89.4%
zLib	0	60.1%	0	87.0%
zFunc	0	60.0%	0	87.0%

Summary

- ➢ Performs code reduction for deployed **binaries**.
- ➢ Uses **heuristics** to infer related code for given test cases.
- ➢ Limitations:
  - ○ Original code section is not removed.
  - ○ Not 100% guaranteed robust.

Applications

- ➢ Legacy software on IoT devices.
- ➢ Software used for very specific purposes.
  - ○ Per-site browser isolation
  - ○ Bloated sensor software
    (e.g., optical, temperature, biometric)

Demos

https://github.com/cxreet/razor/wiki

Demo 1

- In this demo, we do not use any heuristics to debloat the binary.
- Run Razor step by step:
  - Trace the runnings.
  - Dump the executed instructions.
  - Instrument the executed instructions.
  - Rewrite the binary.
- To try the demo, please follow the instructions here: https://github.com/cxreet/razor/wiki/A-Simple-Demo-Without-Heuristics

Demo 1

```
🐋  8e22822c2f34 ~/workspace/razor # cd simple-demo/
🐋  8e22822c2f34 ~/workspace/razor/simple-demo # ls
debloat_simple.py  simple  simple.c
🐋  8e22822c2f34 ~/workspace/razor/simple-demo #
```

- simple.c → the demo's source code.
- simple → the demo binary.
- debloat_simple.py → the helper script for running Razor:
  - **-c trace -a *first_argument* -b *second_argument*** : trace the binary with arguments (*first_argument*, *second_argument*).
  - ***-c dump_inst*** : dump the executed instructions.
  - ***-c instrument*** : instrument the executed instructions.
  - ***-c rewrite*** : rewrite the binary.
  - ***-c clean*** : clean the outputs under current directory.

Simple.c

```c
#include <stdio.h>
#include <stdlib.h>

typedef void (*Ftype)();

void printYes() { printf("Yes\n"); }
void printNo() { printf("No\n"); }


int main(int argc, char * argv[]) {

  if (argc != 3) {
    printf("Usage: ./simple [0|1] [y|n]\n"); return -1;
  }

  int taken = atoi(argv[1]);
  char target = argv[2][0];

  if (taken == 1)
    printf("Taken\n");
  else
    printf("Non-taken\n");

  Ftype fptr = NULL;
  if (target == 'y')
    fptr = &printYes;
  else
    fptr = &printNo;

  (*fptr)();

  return 0;
}
```

Simple.c

```c
#include <stdio.h>
#include <stdlib.h>

typedef void (*Ftype)();

void printYes() { printf("Yes\n"); }
void printNo() { printf("No\n"); }


int main(int argc, char * argv[]) {

  if (argc != 3) {
    printf("Usage: ./simple [0|1] [y|n]\n"); return -1;
  }

  int taken = atoi(argv[1]);
  char target = argv[2][0];

  if (taken == 1)
    printf("Taken\n");
  else
    printf("Non-taken\n");

  Ftype fptr = NULL;
  if (target == 'y')
    fptr = &printYes;
  else
    fptr = &printNo;

  (*fptr)();

  return 0;
}
```

Two arguments: ***taken***, ***target***.

Simple.c

```c
#include <stdio.h>
#include <stdlib.h>

typedef void (*Ftype)();

void printYes() { printf("Yes\n"); }
void printNo() { printf("No\n"); }


int main(int argc, char * argv[]) {

  if (argc != 3) {
    printf("Usage: ./simple [0|1] [y|n]\n"); return -1;
  }

  int taken = atoi(argv[1]);
  char target = argv[2][0];

  if (taken == 1)
    printf("Taken\n");
  else
    printf("Non-taken\n");

  Ftype fptr = NULL;
  if (target == 'y')
    fptr = &printYes;
  else
    fptr = &printNo;

  (*fptr)();

  return 0;
}
```

Two arguments: ***taken***, ***target***.

Conditional branch: Print out “Taken” when ***taken*** is 1, else print out “Non-taken”.

Simple.c

```c
#include <stdio.h>
#include <stdlib.h>

typedef void (*Ftype)();

void printYes() { printf("Yes\n"); }
void printNo() { printf("No\n"); }


int main(int argc, char * argv[]) {

  if (argc != 3) {
    printf("Usage: ./simple [0|1] [y|n]\n"); return -1;
  }

  int taken = atoi(argv[1]);
  char target = argv[2][0];

  if (taken == 1)
    printf("Taken\n");
  else
    printf("Non-taken\n");

  Ftype fptr = NULL;
  if (target == 'y')
    fptr = &printYes;
  else
    fptr = &printNo;

  (*fptr)();

  return 0;
}
```

Two arguments: ***taken***, ***target***.

Conditional branch: Print out “Taken” when ***taken*** is 1, else print out “Non-taken”.

Indirect call: It calls “*printYes*” when ***target*** is ‘y’, otherwise, it calls “*printNo*”.

Goal

- Use the following inputs for tracing:
  - taken = 1 or 0, target = ‘y’
- Debloat the binary to only support the inputs used for tracing.

```c
#include <stdio.h>
#include <stdlib.h>

typedef void (*Ftype)();

void printYes() { printf("Yes\n"); }
void printNo() { printf("No\n"); }


int main(int argc, char * argv[]) {

  if (argc != 3) {
    printf("Usage: ./simple [0|1] [y|n]\n"); return -1;
  }

  int taken = atoi(argv[1]);
  char target = argv[2][0];

  if (taken == 1)
    printf("Taken\n");
  else
    printf("Non-taken\n");

  Ftype fptr = NULL;
  if (target == 'y')
    fptr = &printYes;
  else
    fptr = &printNo;

  (*fptr)();

  return 0;
}
```

❶: taken = 1, target = ‘y’
❷: taken = 0, target = ‘y’

```c
#include <stdio.h>
#include <stdlib.h>

typedef void (*Ftype)();

void printYes() { printf("Yes\n"); }
void printNo() { printf("No\n"); }


int main(int argc, char * argv[]) {

  if (argc != 3) {
    [redacted] Remove it!
  }

  int taken = atoi(argv[1]);
  char target = argv[2][0];

  if (taken == 1)
    printf("Taken\n");
  else
    printf("Non-taken\n");

  Ftype fptr = NULL;
  if (target == 'y')
    fptr = &printYes;
  else
    [redacted] Remove it!
  (*fptr)();

  return 0;
}
```

Step 1: Trace the Runnings

```
🐳  ad3d20f94889 ~/workspace/razor/simple-demo # python debloat_simple.py -c trace -a 1 -b y
../tracers/scripts/trace_with_dynamorio.sh ./simple 1 y
+ bin_cmd='./simple 1 y'
++ dirname ../tracers/scripts/trace_with_dynamorio.sh
+ cur_dir=../tracers/scripts
++ readlink -m ../tracers/scripts/../
+ root_dir=/root/workspace/razor/tracers
+ /root/workspace/razor/tracers/dynamorio/bin64/drrun -c /root/workspace/razor/tracers/bin/libcbr_indcall.so -- ./simple 1 y
+ mv /root/workspace/razor/tracers/bin/cbr_indcall.simple.00033.0000.log ./
mkdir -p logs; mv *.log logs/
🐳  ad3d20f94889 ~/workspace/razor/simple-demo # python debloat_simple.py -c trace -a 0 -b y
../tracers/scripts/trace_with_dynamorio.sh ./simple 0 y
+ bin_cmd='./simple 0 y'
++ dirname ../tracers/scripts/trace_with_dynamorio.sh
+ cur_dir=../tracers/scripts
++ readlink -m ../tracers/scripts/../
+ root_dir=/root/workspace/razor/tracers
+ /root/workspace/razor/tracers/dynamorio/bin64/drrun -c /root/workspace/razor/tracers/bin/libcbr_indcall.so -- ./simple 0 y
+ mv /root/workspace/razor/tracers/bin/cbr_indcall.simple.00043.0000.log ./
mkdir -p logs; mv *.log logs/
🐳  ad3d20f94889 ~/workspace/razor/simple-demo # python debloat_simple.py -c merge_log
python ../stitcher/src/merge_log.py ./logs simple
mv logs/simple-trace.log ./
🐳  ad3d20f94889 ~/workspace/razor/simple-demo #
```

- ➢ Razor uses Dynamorio to trace the binary with inputs: (1, y), (0, y)
- ➢ Razor merges the logs for different runnings → ***simple-trace.log***

Tracing Results

```
🐋  ccaa1b4f2a36 ~/workspace/razor/simple-demo # cat simple-trace.log
```

Tracing Results

```
ccaa1b4f2a36 ~/workspace/razor/simple-demo # cat simple-trace.log
```

Executed Basic Blocks

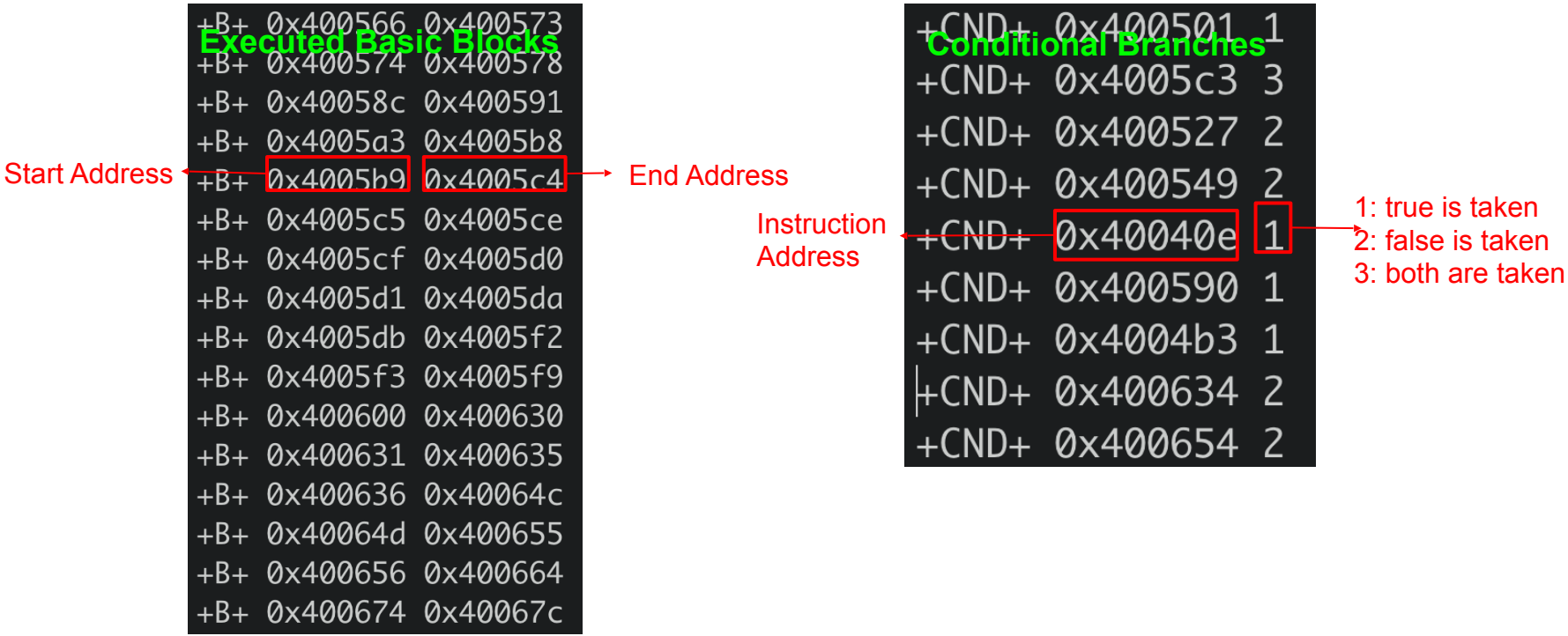
```
+B+ 0x400566 0x400573
+B+ 0x400574 0x400578
+B+ 0x40058c 0x400591
+B+ 0x4005a3 0x4005b8
+B+ 0x4005b9 0x4005c4
+B+ 0x4005c5 0x4005ce
+B+ 0x4005cf 0x4005d0
+B+ 0x4005d1 0x4005da
+B+ 0x4005db 0x4005f2
+B+ 0x4005f3 0x4005f9
+B+ 0x400600 0x400630
+B+ 0x400631 0x400635
+B+ 0x400636 0x40064c
+B+ 0x40064d 0x400655
+B+ 0x400656 0x400664
+B+ 0x400674 0x40067c
```

Start Address

End Address

Tracing Results

```
ccaa1b4f2a36 ~/workspace/razor/simple-demo # cat simple-trace.log
```



Tracing Results

```
ccaa1b4f2a36 ~/workspace/razor/simple-demo # cat simple-trace.log
```

Executed Basic Blocks

```
+B+ 0x400566 0x400573
+B+ 0x400574 0x400578
+B+ 0x40058c 0x400591
+B+ 0x4005a3 0x4005b8
+B+ 0x4005b9 0x4005c4
+B+ 0x4005c5 0x4005ce
+B+ 0x4005cf 0x4005d0
+B+ 0x4005d1 0x4005da
+B+ 0x4005db 0x4005f2
+B+ 0x4005f3 0x4005f9
+B+ 0x400600 0x400630
+B+ 0x400631 0x400635
+B+ 0x400636 0x40064c
+B+ 0x40064d 0x400655
+B+ 0x400656 0x400664
+B+ 0x400674 0x40067c
```

Start Address

End Address

Conditional Branches

```
+CND+ 0x400501 1
+CND+ 0x4005c3 3
+CND+ 0x400527 2
+CND+ 0x400549 2
+CND+ 0x40040e 1
+CND+ 0x400590 1
+CND+ 0x4004b3 1
+CND+ 0x400634 2
+CND+ 0x400654 2
```

Instruction Address

1: true is taken
2: false is taken
3: both are taken

Indirect Calls

```
+IND+ 0x400440 0x400446#2
+IND+ 0x400450 0x400456#2
+IND+ 0x400426 0x7f56238a8430#3 0x7ffa0eb93430#3
+IND+ 0x400649 0x400540#2
+IND+ 0x400430 0x7f56233c3910#1 0x7ffa0e6ae910#1 0x400436#2
+IND+ 0x4005f1 0x400566#2
```

Instruction Address

Target Address # Frequency

Executed Basic Blocks

```
+B+ 0x400566 0x400573
+B+ 0x400574 0x400578
+B+ 0x40058c 0x400591
+B+ 0x4005a3 0x4005b8
+B+ 0x4005b9 0x4005c4
+B+ 0x4005c5 0x4005ce
+B+ 0x4005cf 0x4005d0
+B+ 0x4005d1 0x4005da
+B+ 0x4005db 0x4005f2
+B+ 0x4005f3 0x4005f9
+B+ 0x400600 0x400630
+B+ 0x400631 0x400635
+B+ 0x400636 0x40064c
+B+ 0x40064d 0x400655
+B+ 0x400656 0x400664
+B+ 0x400674 0x40067c
```

```c
#include <stdio.h>
#include <stdlib.h>

typedef void (*Ftype)();

void printYes() { printf("Yes\n"); }
void printNo() { printf("No\n"); }


int main(int argc, char * argv[]) {

  if (argc != 3) {
    printf("Usage: ./simple [0|1] [y|n]\n"); return -1;
  }

  int taken = atoi(argv[1]);
  char target = argv[2][0];

  if (taken == 1)
    printf("Taken\n");
  else
    printf("Non-taken\n");

  Ftype fptr = NULL;
  if (target == 'y')
    fptr = &printYes;
  else
    fptr = &printNo;

  (*fptr)();

  return 0;
}
```

Executed Basic Blocks

```
+B+ 0x400566 0x400573
+B+ 0x400574 0x400578
+B+ 0x40058c 0x400591
+B+ 0x4005a3 0x4005b8
+B+ 0x4005b9 0x4005c4
+B+ 0x4005c5 0x4005ce
+B+ 0x4005cf 0x4005d0
+B+ 0x4005d1 0x4005da
+B+ 0x4005db 0x4005f2
+B+ 0x4005f3 0x4005f9
+B+ 0x400600 0x400630
+B+ 0x400631 0x400635
+B+ 0x400636 0x40064c
+B+ 0x40064d 0x400655
+B+ 0x400656 0x400664
+B+ 0x400674 0x40067c
```

```c
#include <stdio.h>
#include <stdlib.h>

typedef void (*Ftype)();

void printYes() { printf("Yes\n"); }
void printNo() { printf("No\n"); }


int main(int argc, char * argv[]) {

  if (argc != 3) {
    printf("Usage: ./simple [0|1] [y|n]\n"); return -1;
  }

  int taken = atoi(argv[1]);
  char target = argv[2][0];

  if (taken == 1)
    printf("Taken\n");
  else
    printf("Non-taken\n");

  Ftype fptr = NULL;
  if (target == 'y')
    fptr = &printYes;
  else
    fptr = &printNo;

  (*fptr)();

  return 0;
}
```

Executed Basic Blocks

```
+B+ 0x400566 0x400573
+B+ 0x400574 0x400578
+B+ 0x40058c 0x400591
+B+ 0x4005a3 0x4005b8
+B+ 0x4005b9 0x4005c4
+B+ 0x4005c5 0x4005ce
+B+ 0x4005cf 0x4005d0
+B+ 0x4005d1 0x4005da
+B+ 0x4005db 0x4005f2
+B+ 0x4005f3 0x4005f9
+B+ 0x400600 0x400630
+B+ 0x400631 0x400635
+B+ 0x400636 0x40064c
+B+ 0x40064d 0x400655
+B+ 0x400656 0x400664
+B+ 0x400674 0x40067c
```

```c
#include <stdio.h>
#include <stdlib.h>

typedef void (*Ftype)();

void printYes() { printf("Yes\n"); }
void printNo() { printf("No\n"); }


int main(int argc, char * argv[]) {

  if (argc != 3) {
    printf("Usage: ./simple [0|1] [y|n]\n"); return -1;
  }

  int taken = atoi(argv[1]);
  char target = argv[2][0];

  if (taken == 1)
    printf("Taken\n");
  else
    printf("Non-taken\n");

  Ftype fptr = NULL;
  if (target == 'y')
    fptr = &printYes;
  else
    fptr = &printNo;

  (*fptr)();

  return 0;
}
```

Conditional Branches

```
+CND+ 0x400501 1
+CND+ 0x4005c3 3
+CND+ 0x400527 2
+CND+ 0x400549 2
+CND+ 0x40040e 1
+CND+ 0x400590 1
+CND+ 0x4004b3 1
+CND+ 0x400634 2
+CND+ 0x400654 2
```

```c
#include <stdio.h>
#include <stdlib.h>

typedef void (*Ftype)();

void printYes() { printf("Yes\n"); }
void printNo() { printf("No\n"); }


int main(int argc, char * argv[]) {

  if (argc != 3) {
    printf("Usage: ./simple [0|1] [y|n]\n"); return -1;
  }

  int taken = atoi(argv[1]);
  char target = argv[2][0];

  if (taken == 1)
    printf("Taken\n");
  else
    printf("Non-taken\n");

  Ftype fptr = NULL;
  if (target == 'y')
    fptr = &printYes;
  else
    fptr = &printNo;

  (*fptr)();

  return 0;
}
```

Conditional Branches

```
+CND+ 0x400501 1
+CND+ 0x4005c3 3
+CND+ 0x400527 2
+CND+ 0x400549 2
+CND+ 0x40040e 1
+CND+ 0x400590 1
+CND+ 0x4004b3 1
+CND+ 0x400634 2
+CND+ 0x400654 2
```

```c
#include <stdio.h>
#include <stdlib.h>

typedef void (*Ftype)();

void printYes() { printf("Yes\n"); }
void printNo() { printf("No\n"); }


int main(int argc, char * argv[]) {

  if (argc != 3) {
    printf("Usage: ./simple [1] [y|n]\n"); return -1;
  }

  int taken = atoi(argv[1]);
  char target = argv[2][0];

  if (taken == 1)
    printf("Taken\n");
  else
    printf("Non-taken\n");

  Ftype fptr = NULL;
  if (target == 'y')
    fptr = &printYes;
  else
    fptr = &printNo;

  (*fptr)();

  return 0;
}
```

Conditional Branches

```
+CND+ 0x400501 1
+CND+ 0x4005c3 3
+CND+ 0x400527 2
+CND+ 0x400549 2
+CND+ 0x40040e 1
+CND+ 0x400590 1
+CND+ 0x4004b3 1
+CND+ 0x400634 2
+CND+ 0x400654 2
```

```c
#include <stdio.h>
#include <stdlib.h>

typedef void (*Ftype)();

void printYes() { printf("Yes\n"); }
void printNo() { printf("No\n"); }


int main(int argc, char * argv[]) {

  if (argc != 3) {
    printf("Usage: ./simple [1] [y|n]\n"); return -1;
  }

  int taken = atoi(argv[1]);
  char target = argv[2][0];

  if (taken == 1)
    printf("Taken\n");
  else
    printf("Non-taken\n");

  Ftype fptr = NULL;
  if (target == 'y')
    fptr = &printYes;
  else
    fptr = &printNo;

  (*fptr)();

  return 0;
}
```

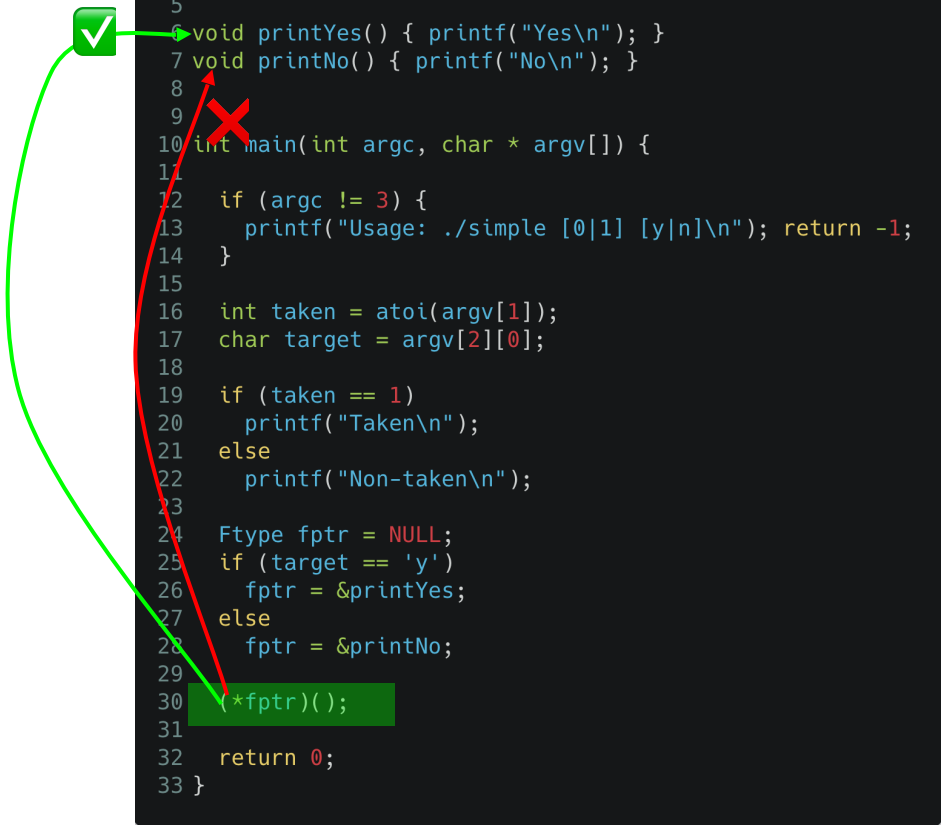
Indirect Calls

```
+IND+ 0x400440 0x400446#2
+IND+ 0x400450 0x400456#2
+IND+ 0x400426 0x7f56238a8430#3
+IND+ 0x400649 0x400540#2
+IND+ 0x400430 0x7f56233c3910#1
+IND+ 0x4005f1 0x400566#2
```

```c
#include <stdio.h>
#include <stdlib.h>

typedef void (*Ftype)();

void printYes() { printf("Yes\n"); }
void printNo() { printf("No\n"); }


int main(int argc, char * argv[]) {

  if (argc != 3) {
    printf("Usage: ./simple [0|1] [y|n]\n"); return -1;
  }

  int taken = atoi(argv[1]);
  char target = argv[2][0];

  if (taken == 1)
    printf("Taken\n");
  else
    printf("Non-taken\n");

  Ftype fptr = NULL;
  if (target == 'y')
    fptr = &printYes;
  else
    fptr = &printNo;

  (*fptr)();

  return 0;
}
```

Indirect Calls

```
+IND+ 0x400440 0x400446#2
+IND+ 0x400450 0x400456#2
+IND+ 0x400426 0x7f56238a8430#3
+IND+ 0x400649 0x400540#2
+IND+ 0x400430 0x7f56233c3910#1
+IND+ 0x4005f1 0x400566#2
```



```c
#include <stdio.h>
#include <stdlib.h>

typedef void (*Ftype)();

void printYes() { printf("Yes\n"); }
void printNo() { printf("No\n"); }


int main(int argc, char * argv[]) {

  if (argc != 3) {
    printf("Usage: ./simple [0|1] [y|n]\n"); return -1;
  }

  int taken = atoi(argv[1]);
  char target = argv[2][0];

  if (taken == 1)
    printf("Taken\n");
  else
    printf("Non-taken\n");

  Ftype fptr = NULL;
  if (target == 'y')
    fptr = &printYes;
  else
    fptr = &printNo;

  (*fptr)();

  return 0;
}
```

Step 2: Dump the Executed Instructions

```
🐳  ad3d20f94889 ~/workspace/razor/simple-demo # python debloat_simple.py -c dump_inst
python ../stitcher/src/instr_dumper.py ./simple-trace.log ./simple ./instr.s
🐳  ad3d20f94889 ~/workspace/razor/simple-demo # cat instr.s
```

- First, Razor disassembles the binary.
- Second, Razor dumps the executed code based on the “executed basic blocks” in traces.
- The executed code is dumped as assembly instructions, which is saved in file ***instr.s***.

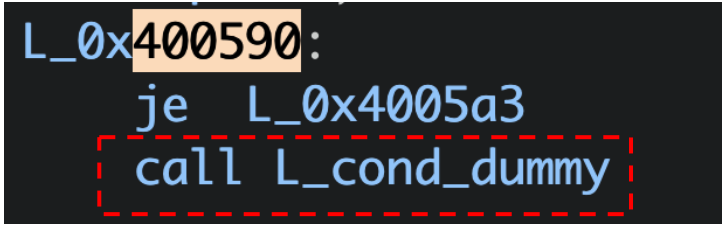
Step 3: Instrument the Executed instructions

```
🐋  ad3d20f94889 ~/workspace/razor/simple-demo # python debloat_simple.py -c instrument
python ../stitcher/src/find_symbols.py ./simple ./instr.s
python ../stitcher/src/stitcher.py ./simple-trace.log ./simple ./simple.s ./callbacks.txt
🐋  ad3d20f94889 ~/workspace/razor/simple-demo # cat ./simple.s
```

- Based on the control flow informations (i.e., conditional branches, indirect calls/jumps), Razor instruments the “conditional branches” and “indirect calls/jumps” in ***instr.s***.
- The instrumented instructions are save in file ***simple.s***.

Conditional Branch Instrumentation

```c
#include <stdio.h>
#include <stdlib.h>

typedef void (*Ftype)();

void printYes() { printf("Yes\n"); }
void printNo() { printf("No\n"); }


int main(int argc, char * argv[]) {

  if (argc != 3) {
    printf("Usage: ./simple [0|1] [y|n]\n"); return -1;
  }

  int taken = atoi(argv[1]);
  char target = argv[2][0];

  if (taken == 1)
    printf("Taken\n");
  else
    printf("Non-taken\n");

  Ftype fptr = NULL;
  if (target == 'y')
    fptr = &printYes;
  else
    fptr = &printNo;

  (*fptr)();

  return 0;
}
```



Conditional Branch Instrumentation

```
1 #include <stdio.h>
2 #include <stdlib.h>
3
4 typedef void (*Ftype)();
5
6 void printYes() { printf("Yes\n"); }
7 void printNo() { printf("No\n"); }
8
9
10 int main(int argc, char * argv[]) {
11
12   if (argc != 3) {
13     printf("Usage: ./simple [0|1] [y|n]\n"); return -1;
14   }
15
16   int taken = atoi(argv[1]);
17   char target = argv[2][0];
18
19   if (taken == 1)
20     printf("Taken\n");
21   else
22     printf("Non-taken\n");
23
24   Ftype fptr = NULL;
25   if (target == 'y')
26     fptr = &printYes;
27   else
28     fptr = &printNo;
29
30   (*fptr)();
31
32   return 0;
33 }
```

```
L_0x400590:
    je  L_0x4005a3
    call L_cond_dummy
```

```
1 #include <stdio.h>
2 #include <stdlib.h>
3
4 typedef void (*Ftype)();
5
6 void printYes() { printf("Yes\n"); }
7 void printNo() { printf("No\n"); }
8
9
10 int main(int argc, char * argv[]) {
11
12   if (argc != 3) {
13     42/0; // Throw Floating Point Exception.
14   }
15
16   int taken = atoi(argv[1]);
17   char target = argv[2][0];
18
19   if (taken == 1)
20     printf("Taken\n");
21   else
22     printf("Non-taken\n");
23
24   Ftype fptr = NULL;
25   if (target == 'y')
26     fptr = &printYes;
27   else
28     fptr = &printNo;
29
30   (*fptr)();
31
32   return 0;
33 }
```

Indirect Call Instrumentation

```c
#include <stdio.h>
#include <stdlib.h>

typedef void (*Ftype)();

void printYes() { printf("Yes\n"); }
void printNo() { printf("No\n"); }


int main(int argc, char * argv[]) {

  if (argc != 3) {
    printf("Usage: ./simple [0|1] [y|n]\n"); return -1;
  }

  int taken = atoi(argv[1]);
  char target = argv[2][0];

  if (taken == 1)
    printf("Taken\n");
  else
    printf("Non-taken\n");

  Ftype fptr = NULL;
  if (target == 'y')
    fptr = &printYes;
  else
    fptr = &printNo;

  (*fptr)();

  return 0;
}
```

```
L_indcall_0x4005f1_target_0x400566:
    cmp rdx, 0x400566
    jne L_indcall_dummy
    call L_0x400566
```

Indirect Call Instrumentation

```c
#include <stdio.h>
#include <stdlib.h>

typedef void (*Ftype)();

void printYes() { printf("Yes\n"); }
void printNo() { printf("No\n"); }


int main(int argc, char * argv[]) {

  if (argc != 3) {
    printf("Usage: ./simple [0|1] [y|n]\n"); return -1;
  }

  int taken = atoi(argv[1]);
  char target = argv[2][0];

  if (taken == 1)
    printf("Taken\n");
  else
    printf("Non-taken\n");

  Ftype fptr = NULL;
  if (target == 'y')
    fptr = &printYes;
  else
    fptr = &printNo;

  (*fptr)();

  return 0;
}
```

```
L_indcall_0x4005f1_target_0x400566:
    cmp rdx, 0x400566
    jne L_indcall_dummy
    call L_0x400566
```

```c
#include <stdio.h>
#include <stdlib.h>

typedef void (*Ftype)();

void printYes() { printf("Yes\n"); }


int main(int argc, char * argv[]) {

  if (argc != 3) {
    printf("Usage: ./simple [0|1] [y|n]\n"); return -1;
  }

  int taken = atoi(argv[1]);
  char target = argv[2][0];

  if (taken == 1)
    printf("Taken\n");
  else
    printf("Non-taken\n");

  Ftype fptr = NULL;
  if (target == 'y')
    fptr = &printYes;
  if (fptr == &printYes)
    printYes()
  else
    43/0; // Throw Floating Point Exception
  return 0;
}
```

Step 4: Rewrite the Binary

```
🐳  ad3d20f94889 ~/workspace/razor/simple-demo # python debloat_simple.py -c rewrite
python ../stitcher/src/merge_bin.py simple simple.s
🐳  ad3d20f94889 ~/workspace/razor/simple-demo #
```

- Razor compiles the instrumented instructions (i.e., *simple.s*) into an object file.
- Razor rewrites the original binary with the object file.
- The debloated binary is ***./simple_temp/simple.debloated***.

The Debloated Binary

```c
#include <stdio.h>
#include <stdlib.h>

typedef void (*Ftype)();

void printYes() { printf("Yes\n"); }
void printNo() { printf("No\n"); }


int main(int argc, char * argv[]) {

  if (argc != 3) {
    printf("Usage: ./simple [0|1] [y|n]\n"); return -1;
  }

  int taken = atoi(argv[1]);
  char target = argv[2][0];

  if (taken == 1)
    printf("Taken\n");
  else
    printf("Non-taken\n");

  Ftype fptr = NULL;
  if (target == 'y')
    fptr = &printYes;
  else
    fptr = &printNo;

  (*fptr)();

  return 0;
}
```

```c
#include <stdio.h>
#include <stdlib.h>

typedef void (*Ftype)();

void printYes() { printf("Yes\n"); }
[redacted]


int main(int argc, char * argv[]) {

  if (argc != 3) {
    42/0; // Throw Floating Point Exception.
  }

  int taken = atoi(argv[1]);
  char target = argv[2][0];

  if (taken == 1)
    printf("Taken\n");
  else
    printf("Non-taken\n");

  Ftype fptr = NULL;
  if (target == 'y')
    fptr = &printYes;
  if (fptr == &printYes)
    printYes()
  else
    43/0; // Throw Floating Point Exception
  return 0;
}
```

Step 5: Test the Debloated Binary

```
🐋  ccaa1b4f2a36 ~/workspace/razor/simple-demo # ./simple_temp/simple.debloated 0 n
Non-taken
Floating point exception (core dumped)
🐋  ccaa1b4f2a36 ~/workspace/razor/simple-demo # ./simple_temp/simple.debloated 1 n
Taken
Floating point exception (core dumped)
🐋  ccaa1b4f2a36 ~/workspace/razor/simple-demo # ./simple_temp/simple.debloated 0 y
Non-taken
Yes
🐋  ccaa1b4f2a36 ~/workspace/razor/simple-demo # ./simple_temp/simple.debloated 1 y
Taken
Yes
🐋  ccaa1b4f2a36 ~/workspace/razor/simple-demo # ./simple_temp/simple.debloated 1 y 1
Floating point exception (core dumped)
🐋  ccaa1b4f2a36 ~/workspace/razor/simple-demo #
```

- The debloated binary only takes in two arguments, the argument ***taken*** can be any integer, and the argument ***target*** can only be `y`.

- Razor rewrites a binary that supports the same inputs used for tracing.
- For different inputs that share same functionalities with the inputs used for tracing, the debloated binary does not support them. → Over-debloating.
- Razor uses heuristics to infer code not covered by given inputs.

Demo 2

- In this demo, Razor applies different heuristics to debloat the binary.
- Run Razor step by step:
  - Trace the runnings.
  - **Use heuristics to extend the original traces.**
  - Dump the executed instructions.
  - Do the instrumentation.
  - Rewrite the binary.
- To try the demo, please follow the instructions here: https://github.com/cxreet/razor/wiki/A-Simple-Demo-With-Heuristics

Demo 2

```
🐳  ccaa1b4f2a36 ~/workspace/razor/heuristic-demo # cd ~/workspace/razor/heuristic-demo/
🐳  ccaa1b4f2a36 ~/workspace/razor/heuristic-demo # ls
apply_heuristic.sh  debloat_simple.py  simple  simple.c
🐳  ccaa1b4f2a36 ~/workspace/razor/heuristic-demo #
```

- simple.c → the demo's source code.
- simple → the demo binary.
- debloat_simple.py → the helper script for running Razor without heuristics:
  - **-c trace -a *first_argument* -b *second_argument*** : trace the binary with arguments (*first_argument*, *second_argument*).
  - ***-c dump_inst*** : dump the executed instructions.
  - ***-c instrument*** : instrument the executed instructions.
  - ***-c rewrite*** : rewrite the binary.
  - ***-c clean*** : clean the outputs under current directory.
- apply_heuristic.sh → the helper script for running Razor with heuristics.

Simple.c

```c
int main(int argc, char * argv[]) {
    if (argc != 3) {
        printf("Usage: ./simple n1 n2\n");
        return -1;
    }

    int a = atoi(argv[1]);
    int b = atoi(argv[2]);

    test_heuristic_one(a, b);
    test_heuristic_two(a, b);
    test_heuristic_three(a, b);
    test_heuristic_four(a, b);

  return 0;
}
```

- ➔ It takes two arguments: ***a*** and ***b***.
- ➔ The ***main*** function calls four functions:
  - ***test_heuristic_one***
  - ***test_heuristic_two***
  - ***test_heuristic_three***
  - ***test_hrusitic_four***

➢ *test_heuristic_one*

```c
void test_heuristic_one(int a, int b) {
    printf("Testing heuristic one...\n");
    if (a > b) {
        printf("%d > %d\n", a , b);
    }
    printf("Done.\n");

    return;
}
```

➢ *test_heuristic_two*

```c
int test_heuristic_two(int a, int b) {
    printf("Testing heuristic two...\n");
    int ret = 0;
    if (a > b) {
        printf("%d > %d\n", a, b);
        ret = a - b;
    } else {
        ret = b - a;
    }
    printf("Done.\n");
    return ret;
}
```

➢ *test_heuristic_three*

```c
void test_heuristic_three(int a, int b) {
    printf("Testing herusitc three...\n");
    if (a > b) {
        printf("%d > %d\n", a, b);
    } else {
        printf("%d <= %d\n", a, b);
    }
    printf("Done.\n");
}
```

➢ *test_heuristic_four*

```c
void call_new_libcalls(int a, int b) {
        putw(a, stdout);
        printf(" <= ");
        putw(b, stdout);
        printf("\n");
}

void test_heuristic_four(int a, int b) {
    printf("Testing heuristic four...\n");
    if (a > b) {
        printf("%d > %d\n", a, b);
    } else {
        call_new_libcalls(a, b);
    }
    printf("Done.\n");
}
```

What if the inputs for tracing only cover the case when ***a*** > ***b***?

➢ The false branches are removed without heuristics.

```c
void test_heuristic_one(int a, int b) {
    printf("Testing heuristic one...\n");
    if (a > b) {
        printf("%d > %d\n", a , b);
    }
    printf("Done.\n");

    return;
}
```

```c
int test_heuristic_two(int a, int b) {
    printf("Testing heuristic two...\n");
    int ret = 0;
    if (a > b) {
        printf("%d > %d\n", a, b);
        ret = a - b;
    } else {
        ret = b - a;
    }
    printf("Done.\n");
    return ret;
}
```

```c
void test_heuristic_three(int a, int b) {
    printf("Testing herusitc three...\n");
    if (a > b) {
        printf("%d > %d\n", a, b);
    } else {
        printf("%d <= %d\n", a, b);
    }
    printf("Done.\n");
}
```

```c
void call_new_libcalls(int a, int b) {
        putw(a, stdout);
        printf(" <= ");
        putw(b, stdout);
        printf("\n");
}

void test_heuristic_four(int a, int b) {
    printf("Testing heuristic four...\n");
    if (a > b) {
        printf("%d > %d\n", a, b);
    } else {
        call_new_libcalls(a, b);
    }
    printf("Done.\n");
}
```

➢ The false branches are removed without heuristics.

```c
void test_heuristic_one(int a, int b) {
    printf("Testing heuristic one...\n");
    if (a > b) {
        printf("%d > %d\n", a , b);
    }
    printf("Done.\n");

    return;
}
```

```c
int test_heuristic_two(int a, int b) {
    printf("Testing heuristic two...\n");
    int ret = 0;
    if (a > b) {
        printf("%d > %d\n", a, b);
        ret = a - b;
    } else {
        ret = b - a;
    }
    printf("Done.\n");
    return ret;
}
```

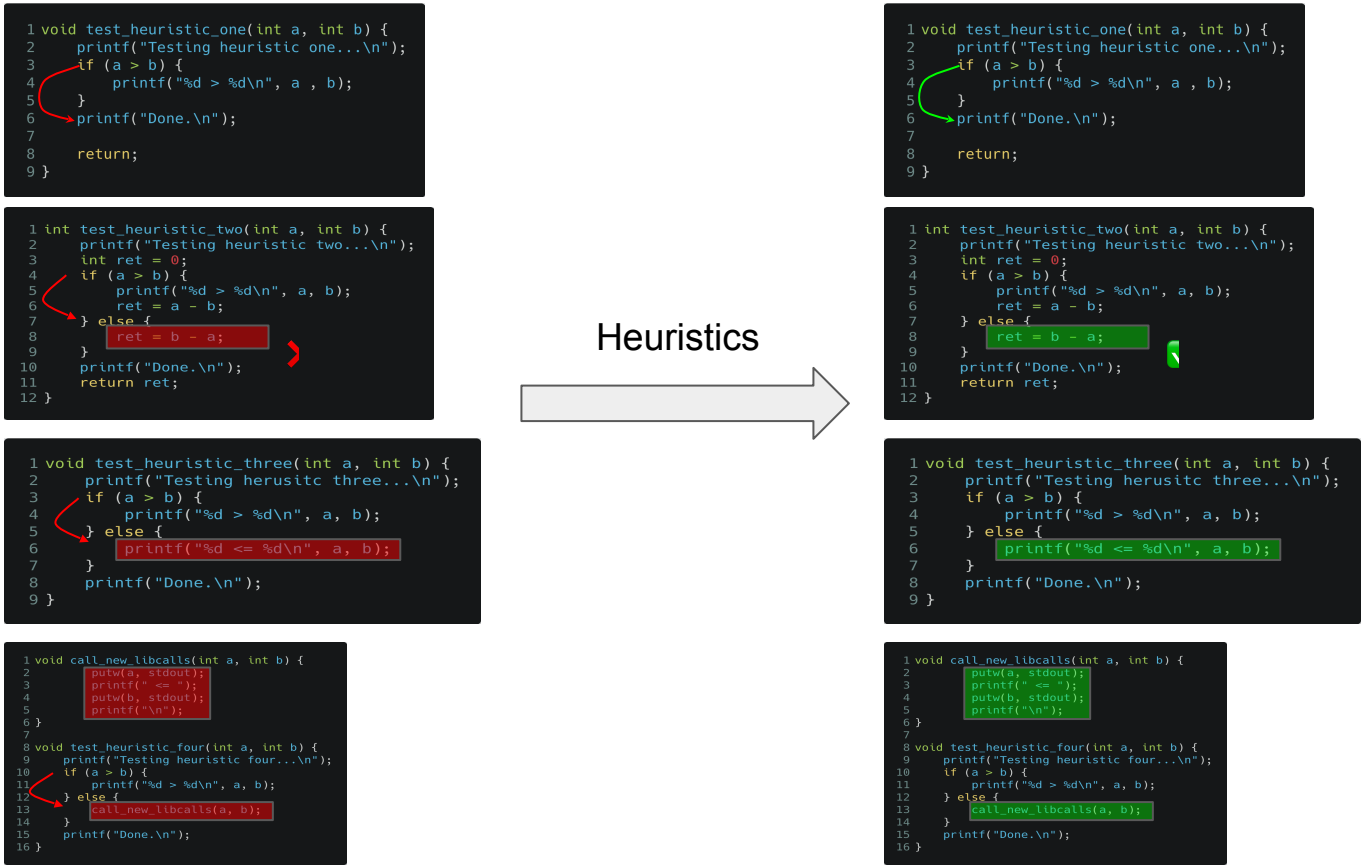
Over-Debloating!

```c
void test_heuristic_three(int a, int b) {
    printf("Testing herusitc three...\n");
    if (a > b) {
        printf("%d > %d\n", a, b);
    } else {
        printf("%d <= %d\n", a, b);
    }
    printf("Done.\n");
}
```

```c
_new_libcalls(int a, int b) {
    utw(a, stdout);
    printf(" <= ");
    putw(b, stdout);
    printf("\n");
}

void test_heuristic_four(int a, int b) {
    printf("Testing heuristic four...\n");
    if (a > b) {
        printf("%d > %d\n", a, b);
    } else {
        call_new_libcalls(a, b);
    }
    printf("Done.\n");
}
```

Goal

- ➢ Use inputs that only covers the ***true*** branches for tracing.
- ➢ Apply heuristics to generate a binary that includes the **false** branches.



Step 1: Trace the Runnings

```
🐳  83e097359693 ~/workspace/razor/heuristic-demo # python debloat_simple.py -c trace -a 2 -b 1
../tracers/scripts/trace_with_dynamorio.sh ./simple 2 1
+ bin_cmd='./simple 2 1'
++ dirname ../tracers/scripts/trace_with_dynamorio.sh
+ cur_dir=../tracers/scripts
++ readlink -m ../tracers/scripts/../
+ root_dir=/root/workspace/razor/tracers
+ /root/workspace/razor/tracers/dynamorio/bin64/drrun -c /root/workspace/razor/tracers/bin/libcbr_indcall.so -- ./simple 2 1
+ mv /root/workspace/razor/tracers/bin/cbr_indcall.simple.00036.0000.log ./
mkdir -p logs; mv *.log logs/
🐳  83e097359693 ~/workspace/razor/heuristic-demo # python debloat_simple.py -c merge_log
python ../stitcher/src/merge_log.py ./logs simple
mv logs/simple-trace.log ./
🐳  83e097359693 ~/workspace/razor/heuristic-demo #
```

- Use Dynamorio to trace the binary with the input: (a = 2, b = 1).
- The tracing results are saved in the file ***simple-trace.log***.

Step 2 & 3: Dump Executed Instructions and Instrument

```
🐳  83e097359693 ~/workspace/razor/heuristic-demo # python debloat_simple.py -c dump_inst
python ../stitcher/src/instr_dumper.py ./simple-trace.log ./simple ./instr.s
🐳  83e097359693 ~/workspace/razor/heuristic-demo # python debloat_simple.py -c instrument
python ../stitcher/src/find_symbols.py ./simple ./instr.s
```

- Step 2: Dump the executed instructions **without** heuristics.
  - First, Razor disassembles the binary.
  - Second, Razor dumps the executed code based on the “executed basic blocks” in traces.
  - The executed code is dumped as assembly instructions, which is saved in file ***instr.s***.
- Step 3: Instrument the executed instructions.
  - Based on the control flow informations (i.e., conditional branches, indirect calls/jumps), Razor instruments the “conditional branches” and “indirect calls/jumps” in ***instr.s***.
  - The instrumented instructions are save in file ***simple.s***.

Step 4 & 5: Rewrite the Binary and Run the Debloated Binary

```
🐳  83e097359693 ~/workspace/razor/heuristic-demo # python debloat_simple.py -c rewrite
python ../stitcher/src/merge_bin.py simple simple.s
🐳  83e097359693 ~/workspace/razor/heuristic-demo # ./simple_temp/simple.debloated 2 1
Testing heuristic one...
2 > 1
Done.
Testing heuristic two...
2 > 1
Done.
Testing herusitc three...
2 > 1
Done.
Testing heuristic four...
2 > 1
Done.
🐳  83e097359693 ~/workspace/razor/heuristic-demo # ./simple_temp/simple.debloated 1 2
Testing heuristic one...
Floating point exception
🐳  83e097359693 ~/workspace/razor/heuristic-demo #
```

```c
void test_heuristic_one(int a, int b) {
    printf("Testing heuristic one...\n");
    if (a > b) {
        printf("%d > %d\n", a , b);
    }
    printf("Done.\n");

    return;
}
```

```c
int test_heuristic_two(int a, int b) {
    printf("Testing heuristic two...\n");
    int ret = 0;
    if (a > b) {
        printf("%d > %d\n", a, b);
        ret = a - b;
    } else {
        ret = b - a;
    }
    printf("Done.\n");
    return ret;
}
```

```c
void test_heuristic_three(int a, int b) {
    printf("Testing herusitc three...\n");
    if (a > b) {
        printf("%d > %d\n", a, b);
    } else {
        printf("%d <= %d\n", a, b);
    }
    printf("Done.\n");
}
```

```c
void call_new_libcalls(int a, int b) {
    putw(a, stdout);
    printf(" <= ");
    putw(b, stdout);
    printf("\n");
}

void test_heuristic_four(int a, int b) {
    printf("Testing heuristic four...\n");
    if (a > b) {
        printf("%d > %d\n", a, b);
    } else {
        call_new_libcalls(a, b);
    }
    printf("Done.\n");
}
```

- Step 4: Rewrite the binary.
  - Razor compiles the instrumented instructions (i.e., *simple.s*) into an object file.
  - Razor rewrites the original binary with the object file.
  - The debloated binary is ***./simple_temp/simple.debloated***.

Step 4 & 5: Rewrite the Binary and Run the Debloated Binary

```
83e097359693 ~/workspace/razor/heuristic-demo # python debloat_simple.py -c rewrite
python ../stitcher/src/merge_bin.py simple simple.s
83e097359693 ~/workspace/razor/heuristic-demo # ./simple_temp/simple.debloated 2 1
Testing heuristic one...
2 > 1
Done.
Testing heuristic two...
2 > 1
Done.
Testing herusitc three...
2 > 1
Done.
Testing heuristic four...
2 > 1
Done.
83e097359693 ~/workspace/razor/heuristic-demo # ./simple_temp/simple.debloated 1 2
Testing heuristic one...
Floating point exception
83e097359693 ~/workspace/razor/heuristic-demo #
```

Only **true** branches are triggered!

```c
void test_heuristic_one(int a, int b) {
    printf("Testing heuristic one...\n");
    if (a > b) {
        printf("%d > %d\n", a , b);
    }
    printf("Done.\n");

    return;
}
```

```c
int test_heuristic_two(int a, int b) {
    printf("Testing heuristic two...\n");
    int ret = 0;
    if (a > b) {
        printf("%d > %d\n", a, b);
        ret = a - b;
    } else {
        ret = b - a;
    }
    printf("Done.\n");
    return ret;
}
```

```c
void test_heuristic_three(int a, int b) {
    printf("Testing herusitc three...\n");
    if (a > b) {
        printf("%d > %d\n", a, b);
    } else {
        printf("%d <= %d\n", a, b);
    }
    printf("Done.\n");
}
```

```c
void call_new_libcalls(int a, int b) {
    putw(a, stdout);
    printf(" <= ");
    putw(b, stdout);
    printf("\n");
}

void test_heuristic_four(int a, int b) {
    printf("Testing heuristic four...\n");
    if (a > b) {
        printf("%d > %d\n", a, b);
    } else {
        call_new_libcalls(a, b);
    }
    printf("Done.\n");
}
```

- Step 4: Rewrite the binary.
  - Razor compiles the instrumented instructions (i.e., *simple.s*) into an object file.
  - Razor rewrites the original binary with the object file.
  - The debloated binary is ***./simple_temp/simple.debloated***.

Step 4 & 5: Rewrite the Binary and Run the Debloated Binary

```
83e097359693 ~/workspace/razor/heuristic-demo # python debloat_simple.py -c rewrite
python ../stitcher/src/merge_bin.py simple simple.s
83e097359693 ~/workspace/razor/heuristic-demo # ./simple_temp/simple.debloated 2 1
Testing heuristic one...
2 > 1
Done.
Testing heuristic two...
2 > 1
Done.
Testing herusitc three...
2 > 1
Done.
Testing heuristic four...
2 > 1
Done.
83e097359693 ~/workspace/razor/heuristic-demo # ./simple_temp/simple.debloated 1 2
Testing heuristic one...
Floating point exception
83e097359693 ~/workspace/razor/heuristic-demo #
```

Only **true** branches are triggered!

False branches are triggered!

```c
void test_heuristic_one(int a, int b) {
    printf("Testing heuristic one...\n");
    if (a > b) {
        printf("%d > %d\n", a , b);
    }
    printf("Done.\n");

    return;
}
```

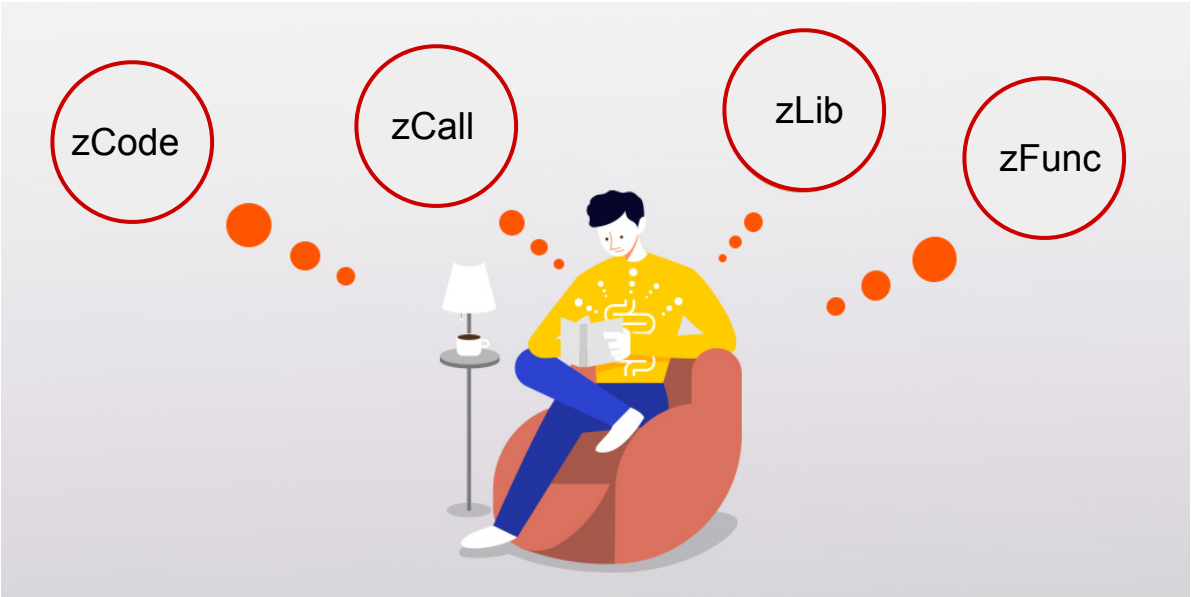
```c
int test_heuristic_two(int a, int b) {
    printf("Testing heuristic two...\n");
    int ret = 0;
    if (a > b) {
        printf("%d > %d\n", a, b);
        ret = a - b;
    } else {
        ret = b - a;
    }
    printf("Done.\n");
    return ret;
}
```

```c
void test_heuristic_three(int a, int b) {
    printf("Testing herusitc three...\n");
    if (a > b) {
        printf("%d > %d\n", a, b);
    } else {
        printf("%d <= %d\n", a, b);
    }
    printf("Done.\n");
}
```

```c
void call_new_libcalls(int a, int b) {
    putw(a, stdout);
    printf(" <= ");
    putw(b, stdout);
    printf("\n");
}

void test_heuristic_four(int a, int b) {
    printf("Testing heuristic four...\n");
    if (a > b) {
        printf("%d > %d\n", a, b);
    } else {
        call_new_libcalls(a, b);
    }
    printf("Done.\n");
}
```

- Step 4: Rewrite the binary.
  - Razor compiles the instrumented instructions (i.e., *simple.s*) into an object file.
  - Razor rewrites the original binary with the object file.
  - The debloated binary is ***./simple_temp/simple.debloated***.

Let’s try the heuristics!



➢ Apply Heuristic **zCode**

```
🐳  83e097359693 ~/workspace/razor/heuristic-demo # ./apply_heuristic.sh 1
+ python ../stitcher/src/heuristic/disasm.py ./simple ./simple.asm
objdump -d -w --insn-width=16 ./simple > .tmp.asm
rm .tmp.asm
+ python ../stitcher/src/heuristic/find_more_paths.py ./simple.asm ./simple-trace.log ./simple-extended.log 1
reading trace and constructing cfg...
identifying jump tables...
```

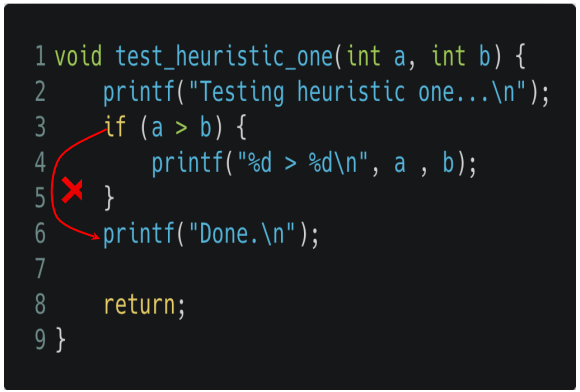
1 → zCode
2 → zCall
3 → zLib
4 → zFunc

➢ Running this command would:
- Use heuristic **zCode** to extend the original trace (i.e., simple-trace.log) and generate the extended trace. → simple-extended.log
- Dump the executed instructions. → instr.s
- Do the instrumentation. → simple.s
- Rewrite the binary. → simple_temp/simple.debloated

Run the Debloated Binary

```
🐋  83e097359693 ~/workspace/razor/heuristic-demo # ./simple_temp/simple.debloated 1 2
Testing heuristic one...
Done.
Testing heuristic two...
Floating point exception
🐋  83e097359693 ~/workspace/razor/heuristic-demo #
```

➢ Applying heuristic **zCode** enables the control flow: line 3 → line 6 in ***test_heuristic_one***.



Run the Debloated Binary

```
🐋  83e097359693 ~/workspace/razor/heuristic-demo # ./simple_temp/simple.debloated 1 2
Testing heuristic one...
Done.
Testing heuristic two...
Floating point exception
🐋  83e097359693 ~/workspace/razor/heuristic-demo #
```

➢ Applying heuristic **zCode** enables the control flow: line 3 → line 6 in ***test_heuristic_one***.

```
1 void test_heuristic_one(int a, int b) {
2     printf("Testing heuristic one...\n");
3     if (a > b) {
4         printf("%d > %d\n", a , b);
5     }
6     printf("Done.\n");
7
8     return;
9 }
```

zCode

```
1 void test_heuristic_one(int a, int b) {
2     printf("Testing heuristic one...\n");
3     if (a > b) {
4         printf("%d > %d\n", a , b);
5     }
6     printf("Done.\n");
7
8     return;
9 }
```

➢ Apply Heuristic **zCall**

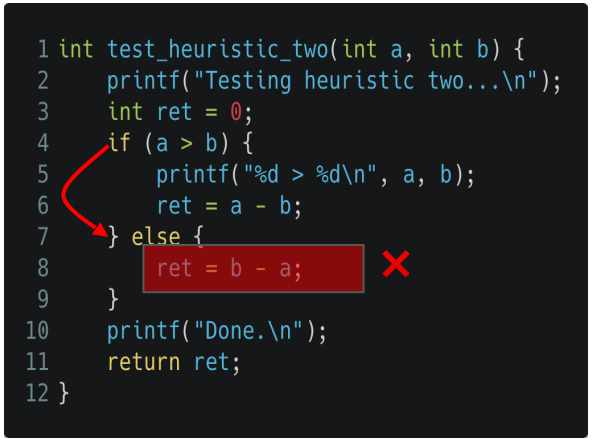
```
🐳  83e097359693 ~/workspace/razor/heuristic-demo # ./apply_heuristic.sh 2
+ python ../stitcher/src/heuristic/disasm.py ./simple ./simple.asm
objdump -d -w --insn-width=16 ./simple > .tmp.asm
rm .tmp.asm
+ python ../stitcher/src/heuristic/find_more_paths.py ./simple.asm ./simple-trace.log ./simple-extended.log 2
reading trace and constructing cfg...
identifying jump tables...
There are  0  jump tables
There are  0 offset tables
```

➢ Running this command would:
- Use heuristic **zCall** to extend the original trace (i.e., simple-trace.log) and generate the extended trace. → simple-extended.log
- Dump the executed instructions. → instr.s
- Do the instrumentation. → simple.s
- Rewrite the binary. → simple_temp/simple.debloated

Run the Debloated Binary

```
🐋  83e097359693 ~/workspace/razor/heuristic-demo # ./simple_temp/simple.debloated 1 2
Testing heuristic one...
Done.
Testing heuristic two...
Done.
Testing herusitc three...
Floating point exception
```

- ➢ Besides enabling the control flow: line 3 → line 6 in ***test_heuristic_one***.
- ➢ Applying heuristic **zCall** adds the **false** branch in ***test_heuristic_two***.



Run the Debloated Binary

```
🐋  83e097359693 ~/workspace/razor/heuristic-demo # ./simple_temp/simple.debloated 1 2
Testing heuristic one...
Done.
Testing heuristic two...
Done.
Testing herusitc three...
Floating point exception
```

- Besides enabling the control flow: line 3 → line 6 in ***test_heuristic_one***.
- Applying heuristic **zCall** adds the **false** branch in ***test_heuristic_two***.

```
1  int test_heuristic_two(int a, int b) {
2      printf("Testing heuristic two...\n");
3      int ret = 0;
4      if (a > b) {
5          printf("%d > %d\n", a, b);
6          ret = a - b;
7      } else {
8          ret = b - a;
9      }
10     printf("Done.\n");
11     return ret;
12 }
```

zCall

```
1  int test_heuristic_two(int a, int b) {
2      printf("Testing heuristic two...\n");
3      int ret = 0;
4      if (a > b) {
5          printf("%d > %d\n", a, b);
6          ret = a - b;
7      } else {
8          ret = b - a;
9      }
10     printf("Done.\n");
11     return ret;
12 }
```

➢ Apply Heuristic **zLib**

```
🐳  83e097359693 ~/workspace/razor/heuristic-demo # ./apply_heuristic.sh 3
+ python ../stitcher/src/heuristic/disasm.py ./simple ./simple.asm
objdump -d -w --insn-width=16 ./simple > .tmp.asm
rm .tmp.asm
+ python ../stitcher/src/heuristic/find_more_paths.py ./simple.asm ./simple-trace.log ./simple-extended.log 3
reading trace and constructing cfg...
identifying jump tables...
There are  0  jump tables
There are  0 offset tables
fixing jmp table targets...
initializing blocks
```

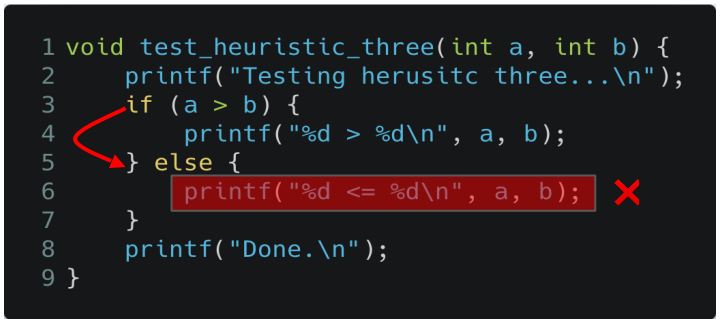
➢ Running this command would:

- Use heuristic **zLib** to extend the original trace (i.e., simple-trace.log) and generate the extended trace. → simple-extended.log
- Dump the executed instructions. → instr.s
- Do the instrumentation. → simple.s
- Rewrite the binary. → simple_temp/simple.debloated

Run the Debloated Binary

```
🐋  83e097359693 ~/workspace/razor/heuristic-demo # ./simple_temp/simple.debloated 1 2
Testing heuristic one...
Done.
Testing heuristic two...
Done.
Testing herusitc three...
1 <= 2
Done.
Testing heuristic four...
Floating point exception
🐋  83e097359693 ~/workspace/razor/heuristic-demo #
```

- Besides **(1)** enableing the control flow: line 3 → line 6 in ***test_heuristic_one***. **(2)** adding the **false** branch in ***test_heuristic_two***.
- Applying heuristic **zLib** adds the **false** branch in ***test_heuristic_three***.



Run the Debloated Binary

```
🐋  83e097359693 ~/workspace/razor/heuristic-demo # ./simple_temp/simple.debloated 1 2
Testing heuristic one...
Done.
Testing heuristic two...
Done.
Testing herusitc three...
1 <= 2
Done.
Testing heuristic four...
Floating point exception
🐋  83e097359693 ~/workspace/razor/heuristic-demo #
```

- Besides **(1)** enableing the control flow: line 3 → line 6 in ***test_heuristic_one***. **(2)** adding the **false** branch in ***test_heuristic_two***.
- Applying heuristic **zLib** adds the **false** branch in ***test_heuristic_three***.

```
1 void test_heuristic_three(int a, int b) {
2     printf("Testing herusitc three...\n");
3     if (a > b) {
4         printf("%d > %d\n", a, b);
5     } else {
6         printf("%d <= %d\n", a, b);
7     }
8     printf("Done.\n");
9 }
```

zLib

```
1 void test_heuristic_three(int a, int b) {
2     printf("Testing herusitc three...\n");
3     if (a > b) {
4         printf("%d > %d\n", a, b);
5     } else {
6         printf("%d <= %d\n", a, b);
7     }
8     printf("Done.\n");
9 }
```

➢ Apply Heuristic **zFunc**

```
🐳  83e097359693 ~/workspace/razor/heuristic-demo # ./apply_heuristic.sh 4
+ python ../stitcher/src/heuristic/disasm.py ./simple ./simple.asm
objdump -d -w --insn-width=16 ./simple > .tmp.asm
rm .tmp.asm
+ python ../stitcher/src/heuristic/find_more_paths.py ./simple.asm ./simple-trace.log ./simple-extended.log 4
reading trace and constructing cfg...
identifying jump tables...
There are  0  jump tables
There are  0 offset tables
fixing jmp table targets...
initializing blocks
```

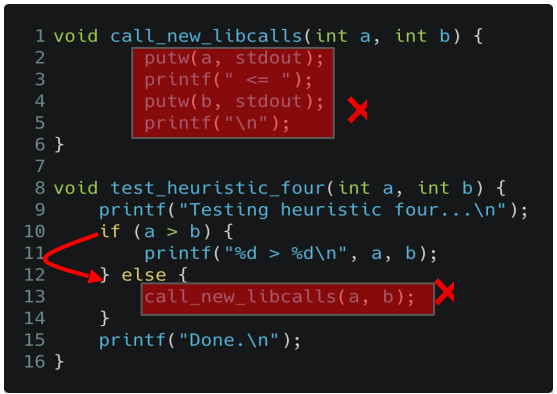
➢ Running this command would:

- Use heuristic **zFunc** to extend the original trace (i.e., simple-trace.log) and generate the extended trace. → simple-extended.log
- Dump the executed instructions. → instr.s
- Do the instrumentation. → simple.s
- Rewrite the binary. → simple_temp/simple.debloated

Run the Debloated Binary

```
83e097359693 ~/workspace/razor/heuristic-demo # ./simple_temp/simple.debloated 1 2
Testing heuristic one...
Done.
Testing heuristic two...
Done.
Testing herusitc three...
1 <= 2
Done.
Testing heuristic four...
 <=
Done.
```

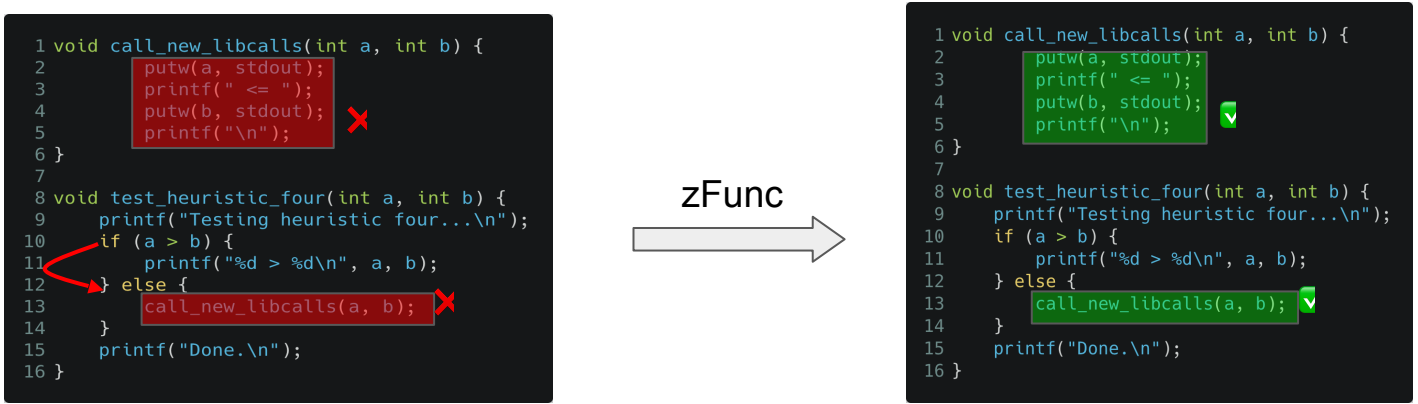
- Besides **(1)** enableing the control flow: line 3 → line 6 in ***test_heuristic_one***. **(2)** adding the **false** branch in ***test_heuristic_two***. **(3)** adding the **false** branch in ***test_heuristic_three***.
- Applying heuristic **zFunc** adds the **false** branch in ***test_heuristic_four***.



Run the Debloated Binary

```
🐋  83e097359693 ~/workspace/razor/heuristic-demo # ./simple_temp/simple.debloated 1 2
Testing heuristic one...
Done.
Testing heuristic two...
Done.
Testing herusitc three...
1 <= 2
Done.
Testing heuristic four...
 <=
Done.
```

- Besides **(1)** enableing the control flow: line 3 → line 6 in ***test_heuristic_one***. **(2)** adding the **false** branch in ***test_heuristic_two***. **(3)** adding the **false** branch in ***test_heuristic_three***.
- Applying heuristic **zFunc** adds the **false** branch in ***test_heuristic_four***.



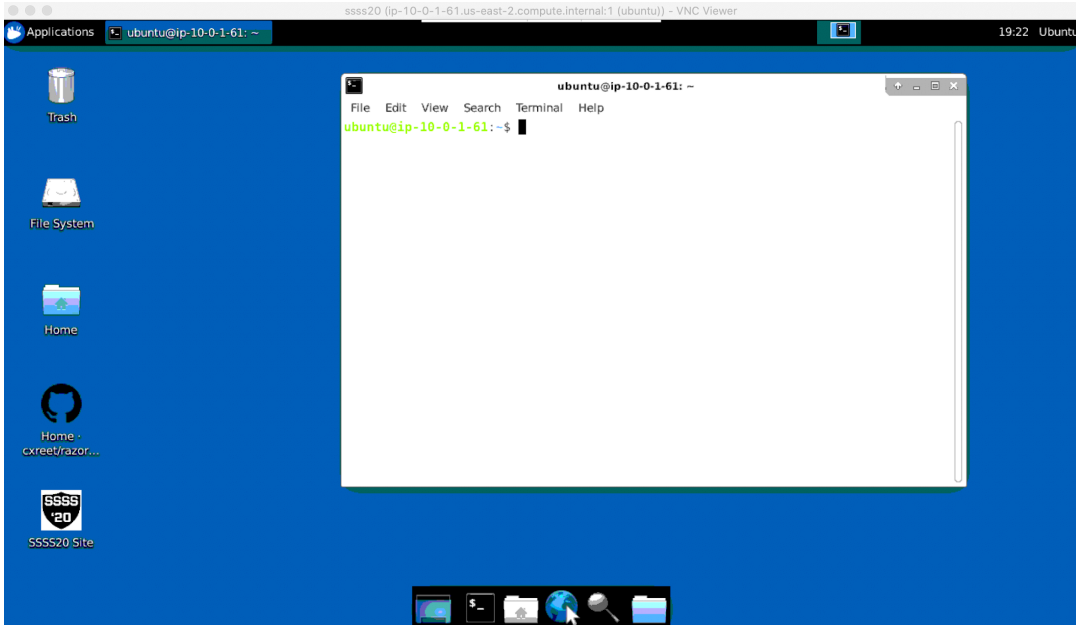
- Razor uses heuristics to infer code not covered by given inputs.
- The debloated binary supports inputs different with the inputs used for tracing but share the same functionality.

Exercises

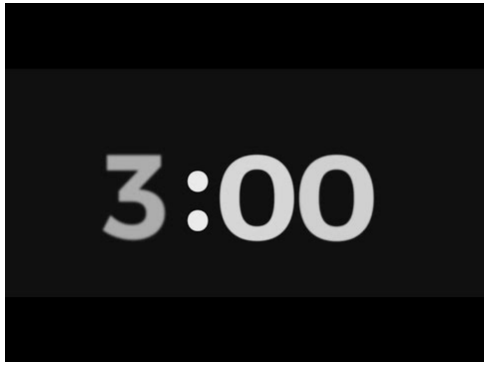
Online Doc: https://github.com/cxreet/razor/wiki/Exercises

Connect to the AWS Instance

```
summer-school-2020 $ ssh -L 5901:127.0.0.1:5901 -J inst1@ssss20.cerias.purdue.edu ubuntu@inst1
Welcome to Ubuntu 18.04.4 LTS (GNU/Linux 5.3.0-1030-aws x86_64)

 * Documentation:  https://help.ubuntu.com
 * Management:     https://landscape.canonical.com
 * Support:        https://ubuntu.com/advantage

  System information as of Mon Jul 13 15:46:52 UTC 2020

  System load:  0.0               Processes:              112
  Usage of /:   75.7% of 7.69GB   Users logged in:        0
  Memory usage: 4%                IP address for eth0:    10.0.1.61
  Swap usage:   0%                IP address for docker0: 172.17.0.1

 * "If you've been waiting for the perfect Kubernetes dev solution for
   macOS, the wait is over. Learn how to install Microk8s on macOS."

   https://www.techrepublic.com/article/how-to-install-microk8s-on-macos/

 * Canonical Livepatch is available for installation.
   - Reduce system reboots and improve kernel security. Activate at:
     https://ubuntu.com/livepatch

9 packages can be updated.
0 updates are security updates.


Last login: Mon Jul 13 15:34:00 2020 from 10.0.0.55
ubuntu@ip-10-0-1-61:~$ ls
Desktop  Documents  Downloads  Music  Pictures  Public  Templates  Videos
```



Pull and Run the Docker Container



- Pull the container:
  - Run the command: ***sudo docker pull chenxiong/razor:0.01***
  - This takes around three minutes.
- Run the container:
  - Run the command: ***sudo docker run --rm -it chenxiong/razor:0.01***

```
workspace $ sudo docker pull chenxiong/razor:0.01
0.01: Pulling from chenxiong/razor
Digest: sha256:018b16122e04f218365a375fc0e8833bddfb832d5c5af86cf68a955e16342f23
Status: Image is up to date for chenxiong/razor:0.01
docker.io/chenxiong/razor:0.01
workspace $ sudo docker run  --rm -it chenxiong/razor:0.01
🐳  83e097359693 ~/workspace/razor #
```

If you see this dolphin, it means you are in the container!

Make sure that you see the dolphin and are under the correct directory.

- Under directory `/root/workspace/razor/benchmarks/core-utilities`, there are 10 programs.
  - Run the command: ***cd ~/workspace/razor/benchmarks/core-utilities/***
  - Run the command: ***ls***

```
🐳  c459a009f08e ~/workspace/razor # cd ~/workspace/razor/benchmarks/core-utilities/
🐳  c459a009f08e ~/workspace/razor/benchmarks/core-utilities # ls
README.md    chown-8.2  grep-2.19   mkdir-5.2.1  sort-8.16  uniq-8.16
bzip2-1.0.5  date-8.21  gzip-1.2.4  rm-8.4       tar-1.14
🐳  c459a009f08e ~/workspace/razor/benchmarks/core-utilities #
```

- Under each program's directory (i.e., **bzip2-1.0.5**):
  - Run the command: ***ls bzip2-1.0.5***

```
🐋  c459a009f08e ~/workspace/razor/benchmarks/core-utilities # ls bzip2-1.0.5/
bzip2-1.0.5.c.orig.c  bzip2.orig  run_razor.py  test  train
```

- Files under each program's directory:
  - bzip2-1.0.5.c.orig.c → the source code.
  - bzip2.orig → the binary.
  - run_razor.py → the helper script that takes commands:
    - **train**: run the binary with the training inputs and collect the traces.
    - **debloat**: debloat the binary with the traces.
    - **extend_debloat**: use heuristics to extend the traces and debloat the binary.
    - **test**: run the debloated binary with testing inputs.
    - **clean**: remove the outputs generated under current directory.
  - train → the directory that contains training inputs if the inputs are files.
  - test → the directory that contains testing inputs if the inputs are files.

- Trace the program with training inputs and get the traces:
  - Run the command: ***cd bzip2-1.0.5/***
  - Run the command: ***python run_razor.py train***

```
c459a009f08e ~/workspace/razor/benchmarks/core-utilities # cd bzip2-1.0.5/
c459a009f08e ~/workspace/razor/benchmarks/core-utilities/bzip2-1.0.5 # python run_razor.py train
running  mkdir -p ./logs
running  cp ../../../tracers/bin/libcbr_indcall.so ./logs/
../../../tracers/dynamorio/bin64/drrun -c ./logs/libcbr_indcall.so -- ./bzip2.orig -c < train/bible.txt > tmp.log
running  ../../../tracers/dynamorio/bin64/drrun -c ./logs/libcbr_indcall.so -- ./bzip2.orig -c < train/bible.txt > tmp.log
../../../tracers/dynamorio/bin64/drrun -c ./logs/libcbr_indcall.so -- ./bzip2.orig -c < train/bib > tmp.log
running  ../../../tracers/dynamorio/bin64/drrun -c ./logs/libcbr_indcall.so -- ./bzip2.orig -c < train/bib > tmp.log
../../../tracers/dynamorio/bin64/drrun -c ./logs/libcbr_indcall.so -- ./bzip2.orig -c < train/obj1 > tmp.log
running  ../../../tracers/dynamorio/bin64/drrun -c ./logs/libcbr_indcall.so -- ./bzip2.orig -c < train/obj1 > tmp.log
../../../tracers/dynamorio/bin64/drrun -c ./logs/libcbr_indcall.so -- ./bzip2.orig -c < train/book1 > tmp.log
```

- The traces would be put under directory *logs*.
  - Run the command: ***ls logs***

```
7bf013a271d6 ~/workspace/razor/benchmarks/core-utilities/bzip2-1.0.5 # ls logs/
cbr_indcall.bzip2.orig.00043.0000.log  cbr_indcall.bzip2.orig.00049.0000.log  cbr_indcall.bzip2.orig.00055.0000.log
cbr_indcall.bzip2.orig.00045.0000.log  cbr_indcall.bzip2.orig.00051.0000.log  cbr_indcall.bzip2.orig.00057.0000.log
cbr_indcall.bzip2.orig.00047.0000.log  cbr_indcall.bzip2.orig.00053.0000.log  cbr_indcall.bzip2.orig.00059.0000.log
```

➢ Debloat the binary:
  - Run the command: ***python run_razor.py debloat***

```
7bf013a271d6 ~/workspace/razor/benchmarks/core-utilities/bzip2-1.0.5 # python run_razor.py debloat
```

➢ To check the outputs:
  - Run the command: ***ls***
  - Run the command: ***ls bzip2.orig_temp/***

```
020734bd5b0b ~/workspace/razor/benchmarks/core-utilities/bzip2-1.0.5 # ls
bzip2-1.0.5.c.orig.c  bzip2-trace.log  bzip2.orig  bzip2.orig_temp  bzip2.s  callbacks.txt  instr.s  logs  run_razor.py  test  tmp.log  train
020734bd5b0b ~/workspace/razor/benchmarks/core-utilities/bzip2-1.0.5 # ls bzip2.orig_temp/
bzip2.o  bzip2.orig  bzip2.orig.debloated  bzip2.s  new_obj_text_content
020734bd5b0b ~/workspace/razor/benchmarks/core-utilities/bzip2-1.0.5 #
```

- ***bzip2-trace.log*** → the merged logs.
- ***instr.s*** → the executed instructions in assembly code format.
- ***bzip2.s*** → the instrumented assembly code.
- ***bzip2.orig_temp/bzip2.orig.debloated*** → the debloated binary.

➢ Run the debloated binary with testing inputs:
  - Run the command: ***python run_razor.py test***

```
020734bd5b0b ~/workspace/razor/benchmarks/core-utilities/bzip2-1.0.5 # python run_razor.py test
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/plrabn12.txt > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/paper6 > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/E.coli > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/asyoulik.txt > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/obj2.bz2 > tmp.log
Floating point exception
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/progc > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/a.txt > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/pi.txt > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/geo > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/ptt5 > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/book2 > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/bible.txt > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/random.txt > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/grammar.lsp > tmp.log
Floating point exception
```

➔ For some testing inputs, the debloated binary failed with **Floating point exception**.

➢ Extend the original traces using heuristic **zCall** and debloat the binary:
  - Run the command: ***python run_razor.py extend_debloat 2***

```
020734bd5b0b ~/workspace/razor/benchmarks/core-utilities/bzip2-1.0.5 # python run_razor.py extend_debloat 2
running  python ../../../stitcher/src/heuristic/disasm.py ./bzip2.orig ./bzip2.orig.asm
objdump -d -w --insn-width=16 ./bzip2.orig > .tmp.asm
rm .tmp.asm
running  python ../../../stitcher/src/heuristic/find_more_paths.py ./bzip2.orig.asm ./bzip2-trace.log ./bzip2-extended.log 2
reading trace and constructing cfg...
identifying jump tables...
There are  0  jump tables
There are  0 offset tables
fixing jmp table targets...
initializing blocks
```

It can be 1, 2, 3, or 4.

- The argument of **extend_debloat**:
  - 1 → **zCode**
  - 2 → **zCall**
  - 3 → **zLib**
  - 4 → **zFunc**

- Run the debloated binary with testing inputs again:
  - Run the command: ***python run_razor.py test***

```
020734bd5b0b ~/workspace/razor/benchmarks/core-utilities/bzip2-1.0.5 # python run_razor.py test
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/plrabn12.txt > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/paper6 > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/E.coli > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/asyoulik.txt > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/obj2.bz2 > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/progc > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/a.txt > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/pi.txt > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/geo > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/ptt5 > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/book2 > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/bible.txt > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/random.txt > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/grammar.lsp > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/xargs.1 > tmp.log
running  ./bzip2.orig_temp/bzip2.orig.debloated -c < test/cp.html > tmp.log
```

- Check the code size of the original binary and the debloated binary:
  - Run the command: ***python ../../../tools/get_code_size.py ./bzip2.orig***
  - Run the command: ***python ../../../tools/get_code_size.py ./bzip2.orig_temp/bzip2.orig.debloated***

```
020734bd5b0b ~/workspace/razor/benchmarks/core-utilities/bzip2-1.0.5 # python ../../../tools/get_code_size.py ./bzip2.orig
LOAD           0x000000 0x0000000000400000 0x0000000000400000 0x01c86c 0x01c86c R E 0x200000
size: 116844
020734bd5b0b ~/workspace/razor/benchmarks/core-utilities/bzip2-1.0.5 # python ../../../tools/get_code_size.py ./bzip2.orig_temp/bzip2.orig.debloated
LOAD           0x036000 0x0000000000700000 0x0000000000700000 0x00b6f2 0x00b6f2 R E 0x1000
size: 46834
020734bd5b0b ~/workspace/razor/benchmarks/core-utilities/bzip2-1.0.5 #
```

- The code size is reduced from 116,844 bytes to 46,834 bytes with the heuristic **zCall**.
  - The code reduction rate (CRR) is:
    - (116844-46834)/116844 = 59.9%.

Exercise #1

- For the 10 programs under directory “/root/workspace/razor/benchmarks/core-utilities”:
  - First, run Razor to debloat the binary without any heuristics. Calculate the code reduction rate (CRR) and the number of failed cases of testing inputs.
  - Then, run Razor to debloat the binary with applying heuristic **zCode**, **zCall**, **zLib**, **zFunc**. Calculate the CRR and the number of failed cases of testing inputs for each heuristic. (Stop at any heuristic if the debloated binary failed zero testing inputs.)
  - Fill the table on the next page.
  - Please following the instructions: https://github.com/cxreet/razor/wiki/Exercises

	None		zCode		zCall		zLib		zFun	
	CRR (%)	# Failed Cases	CRR (%)	# Failed Cases	CRR (%)	# Failed Cases	CRR (%)	# Failed Cases	CRR (%)	# Failed Cases
bzip2										
chown										
date										
grep										
gzip										
mkdir										
rm										
sort										
tar										
uniq										

CRR: code reduction rate.

Exercise #2

- For programs that still got `Floating point exception` after applying the ***zFunc*** heuristic.
  - Why do the heuristics fail?
    - Hint: The output from running command `***extend_debloat 4***` has *"**Missing lib functions**"*.
  - How to solve the exceptions?
    - Hint: `***/root/workspace/razor/stitcher/src/heuristic/libcall.patch***` is used for heuristics to add library calls that share different functionalities with executed code. Each line contains a function name.

Solutions for Exercises

Exercise #1

	None		zCode		zCall		zLib		zFun	
	CRR (%)	# Failed Cases	CRR (%)	# Failed Cases	CRR (%)	# Failed Cases	CRR (%)	# Failed Cases	CRR (%)	# Failed Cases
bzip2	62.4	6	62.4	5	59.9	1	24.8	0		
chown	81.9	17	82.1	17	79.0	17	56.7	10	56.7	10
date	71.2	33	71.4	33	59.8	33	52.8	2	43.4	0
grep	75.3	38	75.4	38	71.1	38	58.3	0		
gzip	79.6	3	79.6	3	76.1	2	75.2	0		
mkdir	75.4	2	75.5	2	67.8	1	37.0	0		
rm	76.5	20	76.7	20	70.7	20	51.7	5	44.9	5
sort	89.2	28	89.3	28	87.4	28	50.5	0		
tar	95.0	1	95.0	1	92.9	0				
uniq	84.2	40	84.3	40	83.2	40	53.6	0		

Exercise #2