Tracking Origins

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Today's Topics

- Exploring History
- Dynamic Slicing
- Leveraging Origins

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Exploring the Past

A typical debugging session looks like this:

1. Set a breakpoint
2. Start program, reaching breakpoint
3. Step, Step, Step, …
4. Oops! I've gone too far!

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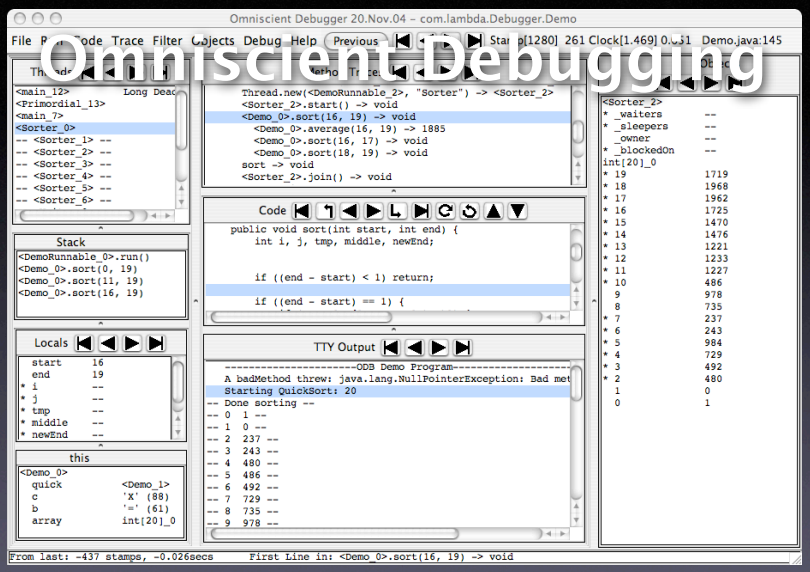

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ODC by Bil Lewis
[Give an interactive demo, using the ODC pre-canned demo download]

How does it work?

- ODB records a *trace* of the entire execution history
- Slows down programs by a factor of 10
- Records about 100 MB/s
- Now available in commercial tools

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Commercially available in RETROVUE and CODEGUIDE

Dynamic Slicing

- Static slices apply to *all* program runs:
  - General + reusable, but imprecise
- A *dynamic slice* applies to *a single run*:
  - Specific and precise

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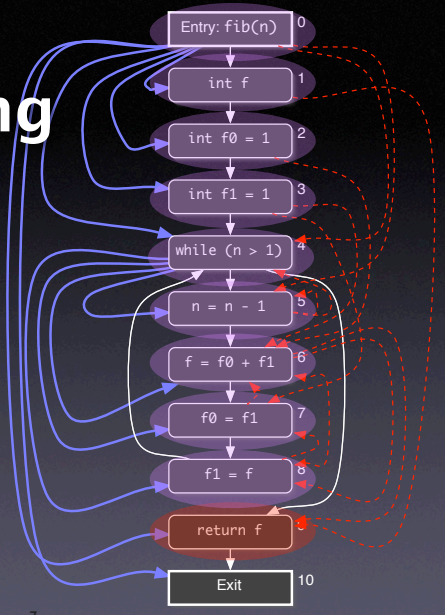
Static Slicing

- Given a statement B, the backward slice contains all statements that could influence the read variables or execution of B
- Formally:

$$S^B(B) = \{A | A \rightarrow^* B\}$$



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```
 1 n = read();
 2 a = read();
 3 x = 1;
 4 b = a + x;
 5 a = a + 1;
 6 i = 1;
 7 s = 0;
 8 while (i <= n) {
 9     if (b > 0)
10         if (a > 1)
11             x = 2;
12     s = s + x;
13     i = i + 1;
14 }
15 write(s);
```

Static slice for (s, 15)

```
 1 n = read(); // n = 2
 2 a = read(); // a = 0
 3 x = 1;
 4 b = a + x;
 5 a = a + 1;
 6 i = 1;
 7 s = 0;
 8 while (i <= n) {
 9     if (b > 0)
10         if (a > 1)
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Dynamic slice for (s, 15)

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```
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 8 while (i <= n) {
 9     if (b > 0)
10         if (a > 1)
11             x = 2;
12     s = s + x;
13     i = i + 1;
14 }
15 write(s);
```

1. Obtain a *trace* of the execution
2. Get the variables that are read and written
3. Assign an empty slice to each written variable
4. Compute the slices from start to end:

$$DynSlice(w) = \bigcup_i (DynSlice(r_i) \cup \{line(r_i)\})$$

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Just a reminder...

Trace	Write	Read	Dynamic Slice
1 n = read();	n		
2 a = read();	a	$DynSlice(w) = \bigcup_i (DynSlice(r_i) \cup \{line(r_i)\})$	
3 x = 1;	x		
4 b = a + x;	b	a, x	2, 3
5 a = a + 1;	a	a	2
6 i = 1;	i		
7 s = 0;	s		
8 while (i <= n) {	p8	i, n	6, 1
9 if (b > 0)	p9	b, p8	4, 2, 3, 8, 6, 1
10 if (a > 1)	p10	a, p9	5, 2, 9, 4, 2, 3, 8, 6, 1
12 s = s + x;	s	s, x, p8	7, 3, 8, 6, 1
13 i = i + 1;	i	i, p8	8, 6, 1
8 while (i <= n) {	p8	i, n	13, 8, 6, 1
9 if (b > 0)	p9	b, p8	4, 2, 3, 13, 8, 6, 1
10 if (a > 1)	p10	a, p9	5, 2, 9, 4, 2, 3, 13, 8, 6, 1
12 s = s + x;	s	s, x, p8	12, 7, 3, 6, 8, 1, 13
13 i = i + 1;	i	i, p8	13, 8, 6, 1
8 while (i <= n) {	p8	i, n	13, 8, 6, 1
15 write(s);	o15	s	12, 7, 3, 6, 8, 1, 13

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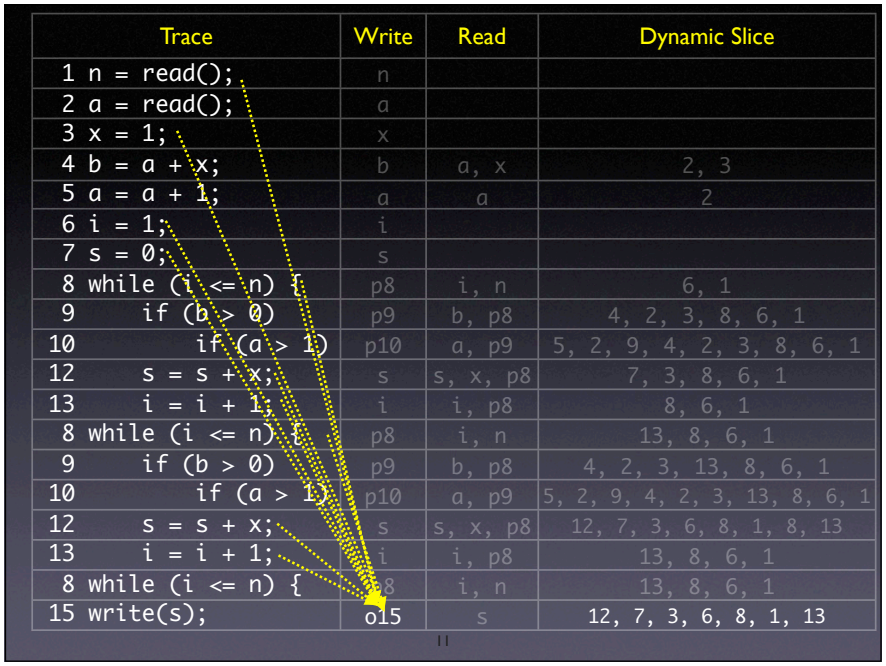

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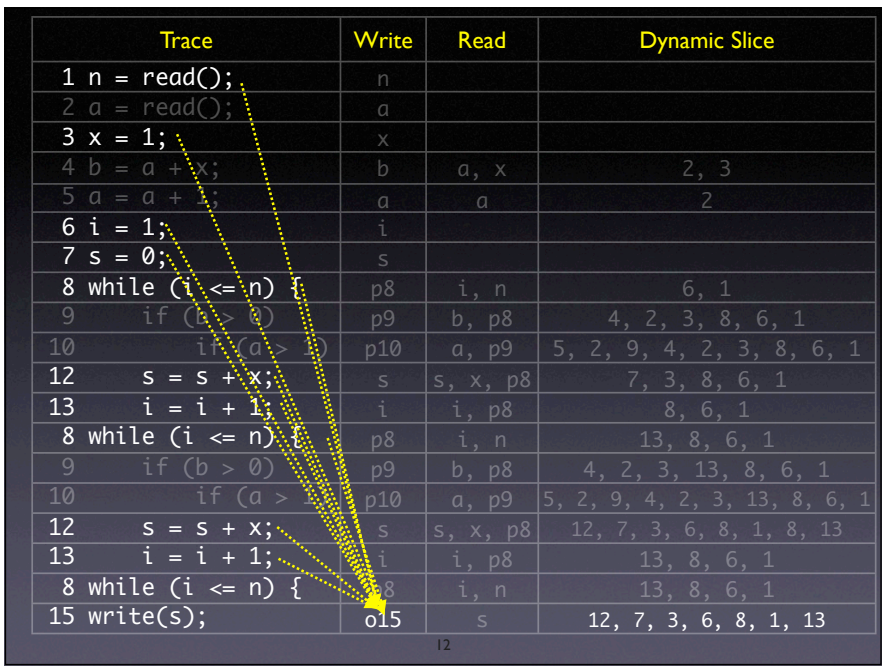

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```
 1 n = read();          1 n = read(); // n = 2
 2 a = read();          2 a = read(); // a = 0
 3 x = 1;               3 x = 1;
 4 b = a + x;           4 b = a + x;
 5 a = a + 1;           5 a = a + 1;
 6 i = 1;               6 i = 1;
 7 s = 0;               7 s = 0;
 8 while (i <= n) {     8 while (i <= n) {
 9     if (b > 0)       9     if (b > 0)
10         if (a > 1)  10         if (a > 1)
11             x = 2;  11             x = 2;
12     s = s + x;      12     s = s + x;
13     i = i + 1;      13     i = i + 1;
14 }                   14 }
15 write(s);          15 write(s);
```

Static slice for (s, 15) Dynamic slice for (s, 15)

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Discussion

- Dynamic slices are much more precise than static slices (applied to the one run, that is)
- From some variable, a backward slice encompasses on average
  - 30% of the *entire* program (static slice)
  - 5% of the *executed* program (dynamic slice)
- Overhead as in omniscient debugging

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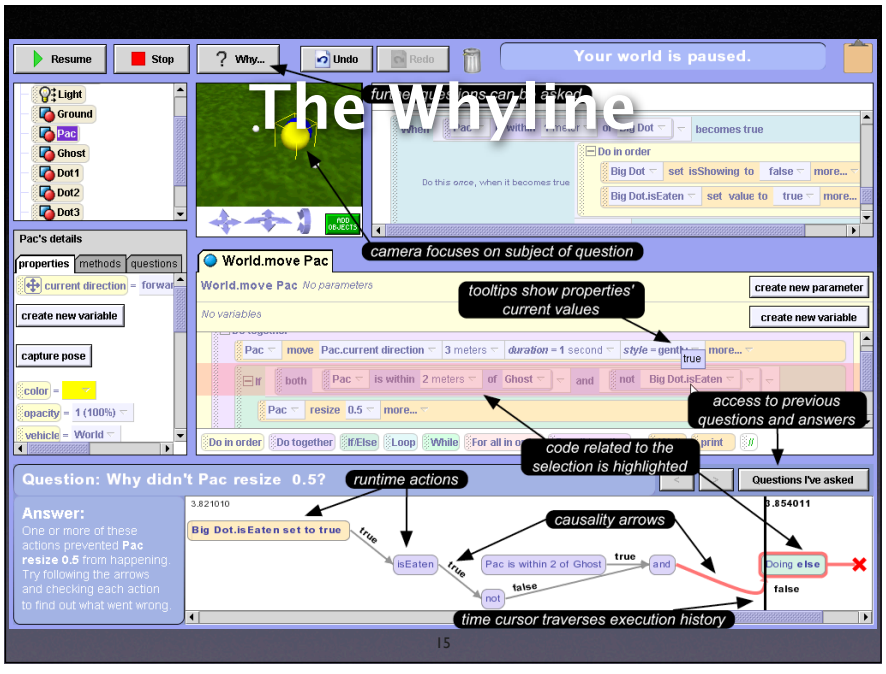

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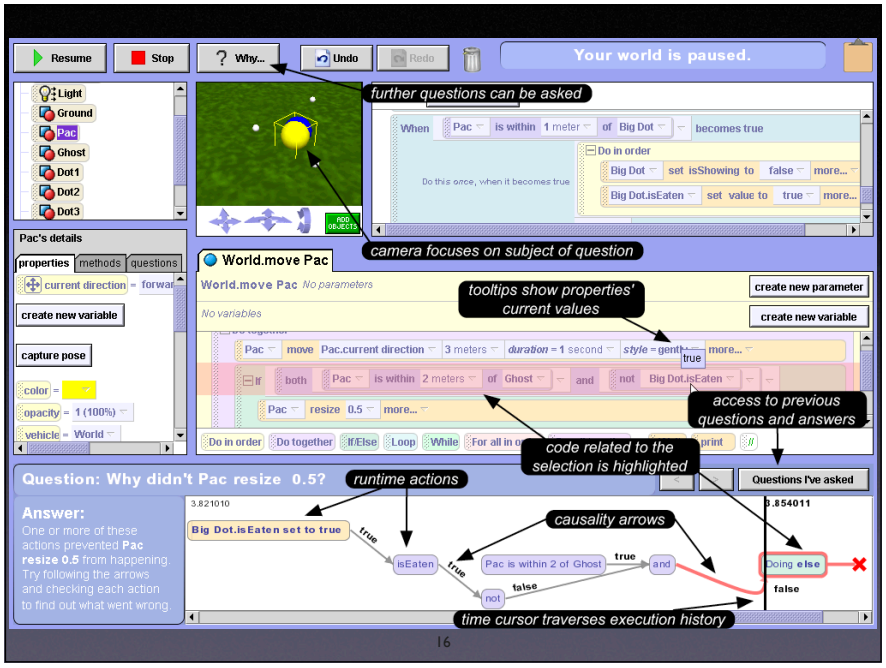
Ko and Myers (2004) from CMU (Human-Computer Interaction)



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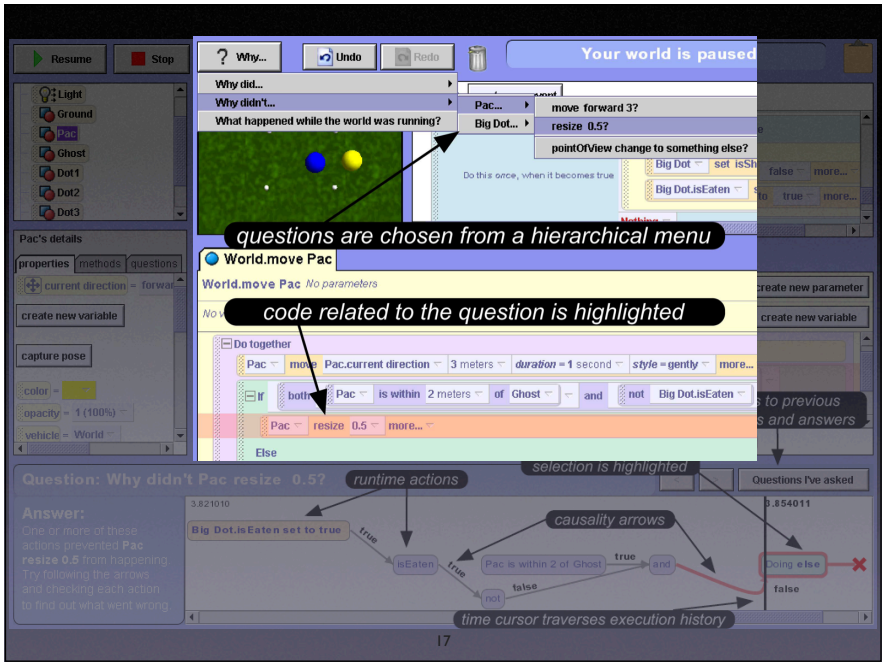

Ko and Myers (2004) from CMU (Human-Computer Interaction)
[switch back and forth between last slide and this slide]

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"Why did" questions

- Take the dynamic slice of the variable
- Follow at most two dependencies
- If programmer wants to, follow dependencies transitively

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“Why did s = 2 in Line 15?”

```
 1 n = read(); // n = 2
 2 a = read(); // a = 0
 3 x = 1;
 4 b = a + x;
 5 a = a + 1;
 6 i = 1;
 7 s = 0;
 8 while (i <= n) {
 9     if (b > 0)
10         if (a > 1)
11             x = 2;
12     s = s + x;
13     i = i + 1;
14 }
15 write(s);
```

“B 2”

Take the dynamic slice of the variable

Follow at most two dependencies

If programmer wants to, follow dependencies transitively

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“Why didn’t” questions

- Follow back control dependencies to closest controlling statement(s)
- Do a “why did” question on each
- Again, follow at most two dependencies

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“Why didn’t x = 2 in Line 11?”

```
 1 n = read(); // n = 2
 2 a = read(); // a = 0
 3 x = 1;
 4 b = a + x;
 5 a = a + 1;
 6 i = 1;
 7 s = 0;
 8 while (i <= n) {
 9     if (b > 0)
10         if (a > 1)
11             x = 2;
12     s = s + x;
13     i = i + 1;
14 }
15 write(s);
```

“B l”

Follow back control dependencies to closest controlling statement(s)

Do a “why did” question on each

Again, follow at most two dependencies

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Discussion

The WHYLINE combines

- omniscient debugging
- static slicing
- dynamic slicing

in an attractive package, showcasing the state of the art in interactive debugging

Tracking Infections

1. Start with the infected value as seen in the failure
2. Follow back the dependencies
3. Observe and judge origins – are they sane?
4. If some origin is infected, repeat at Step 2
5. All origins are sane? Here's the infection site!

Concepts

★ Omniscient debugging allows for simple exploration of the entire execution history

★ Dynamic slicing tells the origin of a value

★ To track down an infection, follow dependencies and observe origins, repeating the process for infected origins

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