

On Time-aware Instrumentation of Programs

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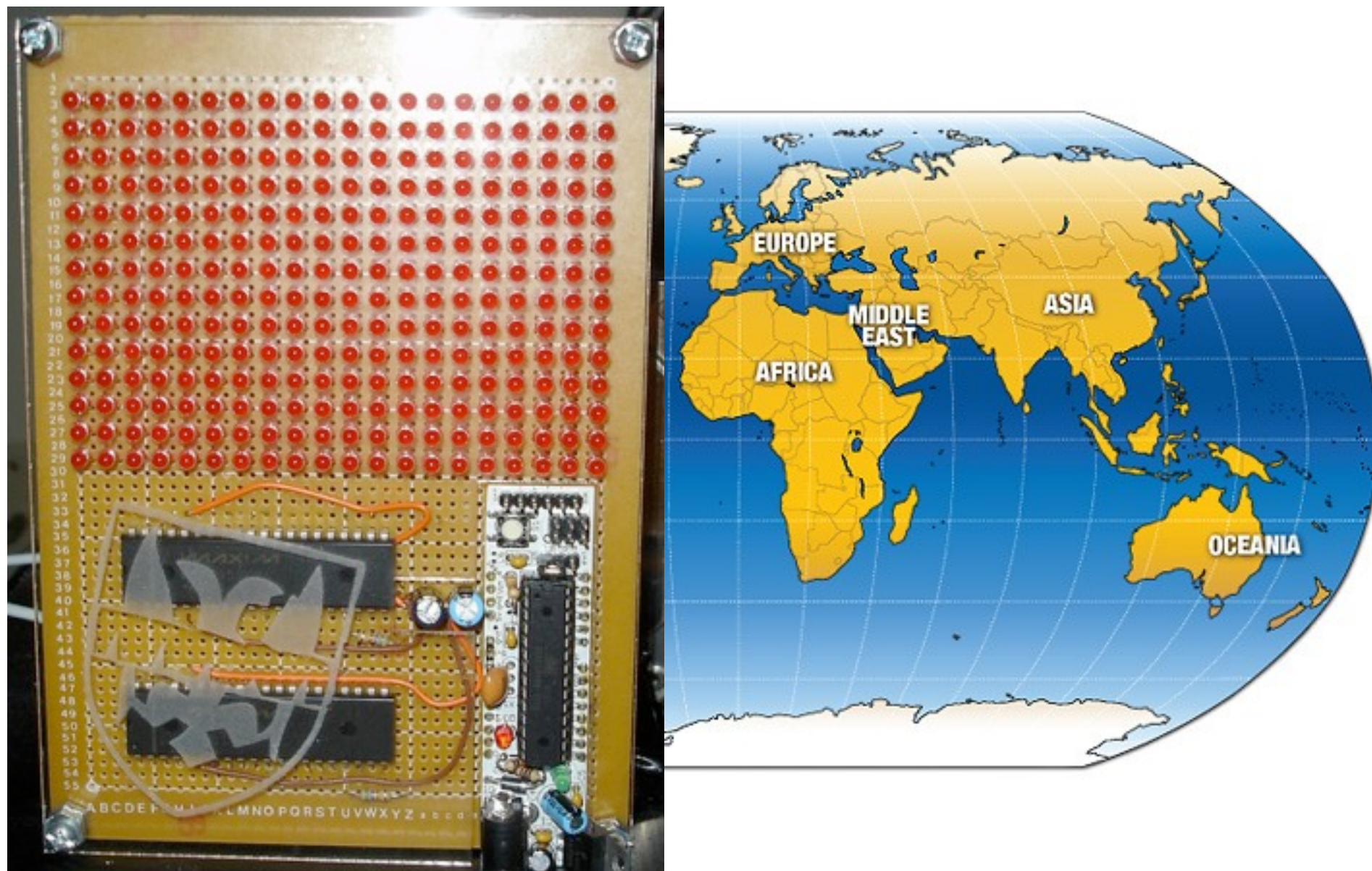
Motivation

- Hard real-time systems
- Background/foreground programs
- Real-time embedded systems are notoriously hard to debug
- 30-50% of development costs are testing and debugging



Do you Believe in LED-based Debugging?

Your planetary-scale debugging array:



Tracing

- Record online, replay offline

```

-10  0x010009D8  0020  LSL  R0,R4,#0
-9   0x010009DA  3820  SUB  R0,#__stdou
-8   0x010009DC  BC10  POP  {R4}
-7   0x010009DE  BC08  POP  {R3}
-6   0x010009E0  4718  BX   R3
-5   0x01000300  5530  STRB R0,[R6,R4]
-4   0x01000302  1C64  ADD  R4,R4,#1
-3   0x01000304  5D30  LDRB R0,[R6,R4]
-2   0x01000306  2800  CMP  R0,#0x00
-1   0x01000308  D1F8  BNE  0x010002FC

200:      for (i = 0; cmdbuf[i] == ' '; i++);
201:
0x0100030A  E000  B    0x0100030E
0x0100030C  1C40  ADD  R0,R0,#1
0x0100030E  5C31  LDRB R1,[R6,R0]
0x01000310  2920  CMP  R1,#__stdout(0x20)
0x01000312  D0FB  BEQ  0x0100030C

202:      switch (cmdbuf[i]) {
203:
204:          case 'R':
205:              if ((idx = read_index (&cmdbuf[i+1]
206:                  while (idx != sindex) {
207:                      if (US0_CSR & US_RXRDY) {

```

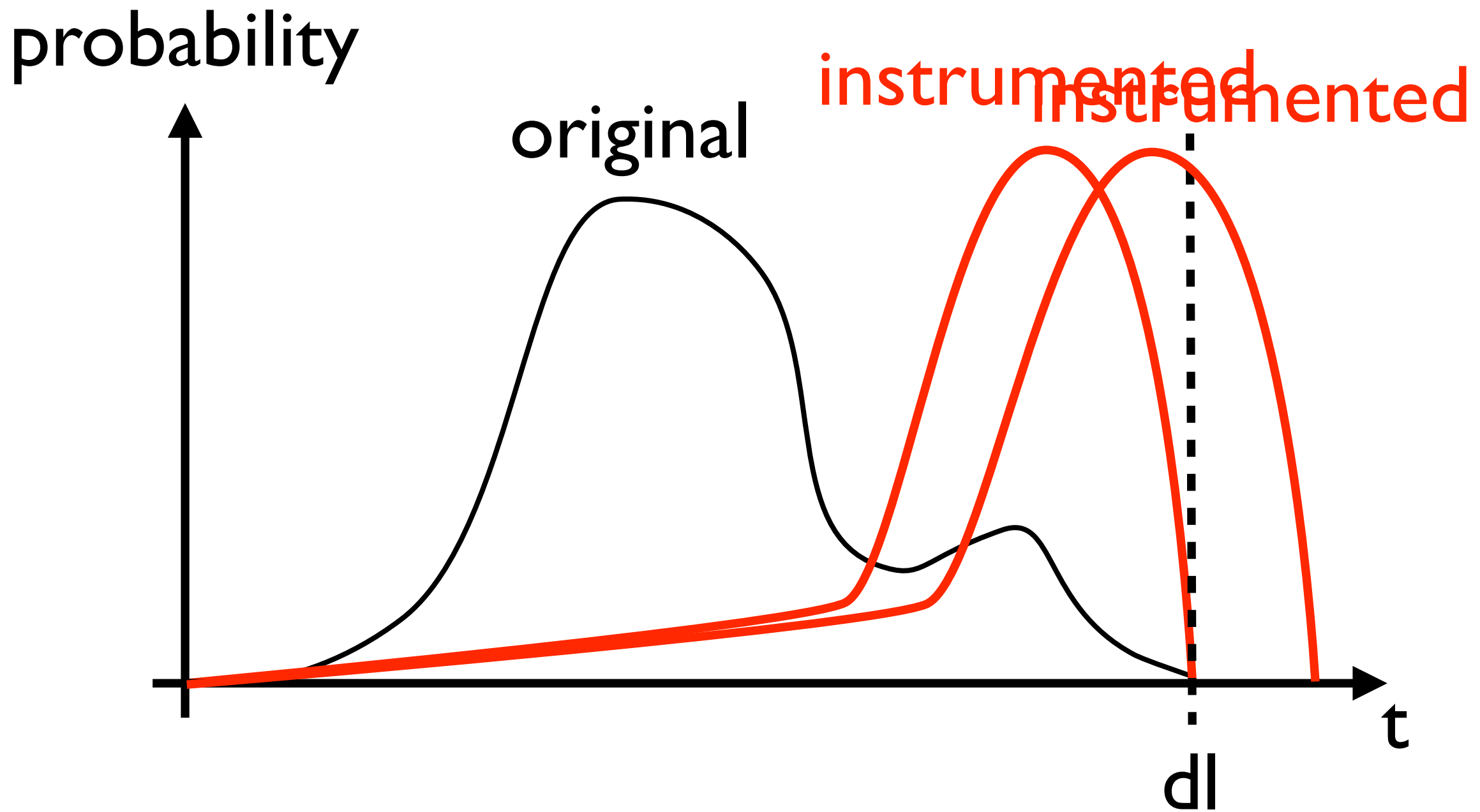

Problem Definition

- How can we automate capturing runtime behavior while minimizing timing interference?
- Where in the code should you capture information?
- What to do when you can't capture all?
- What size do you need for your trace buffer?

Key Ideas in a Nutshell

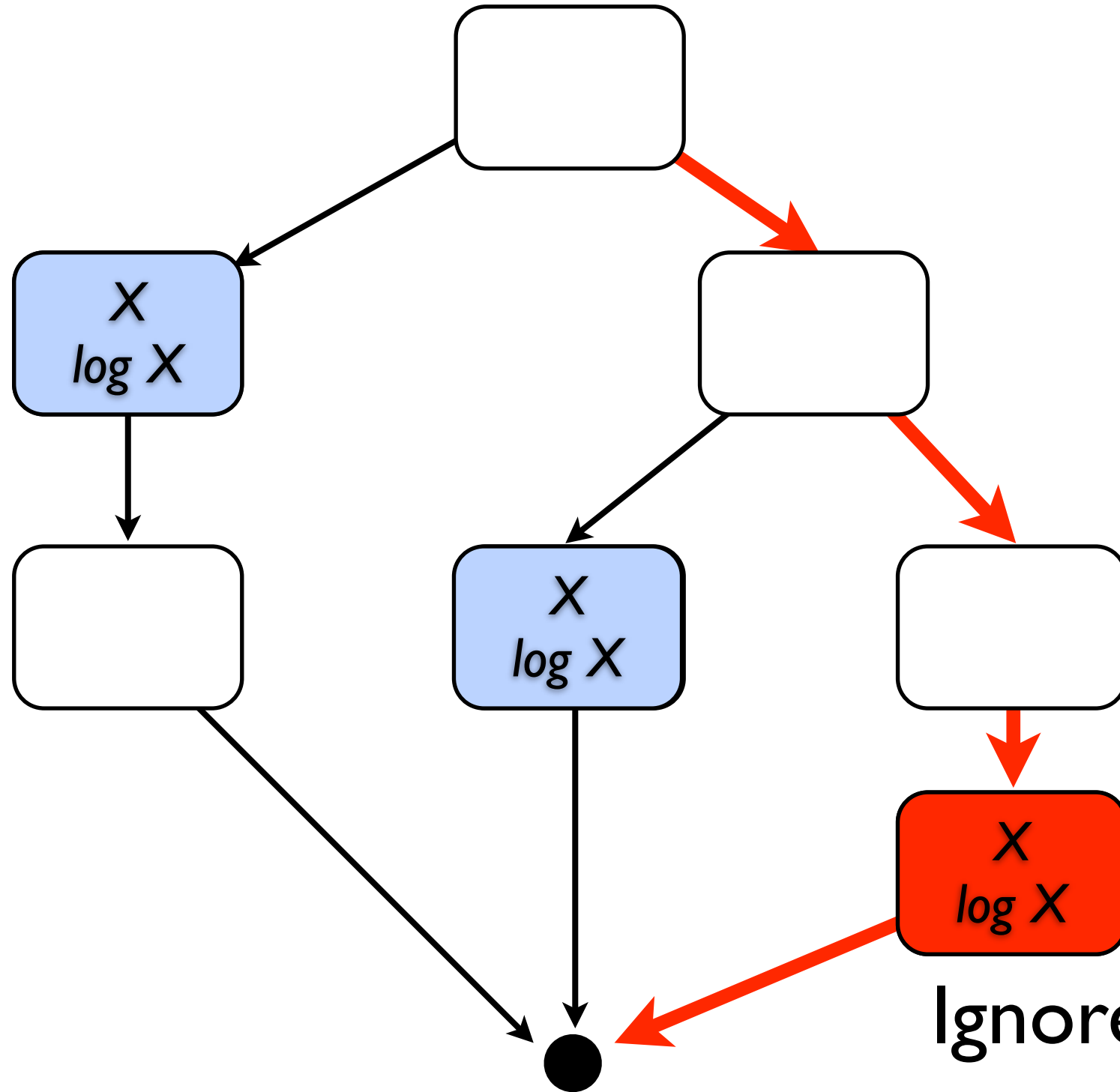
6

But what if it doesn't fit?



Tradeoff: *partial trace & trace reliability*

Example

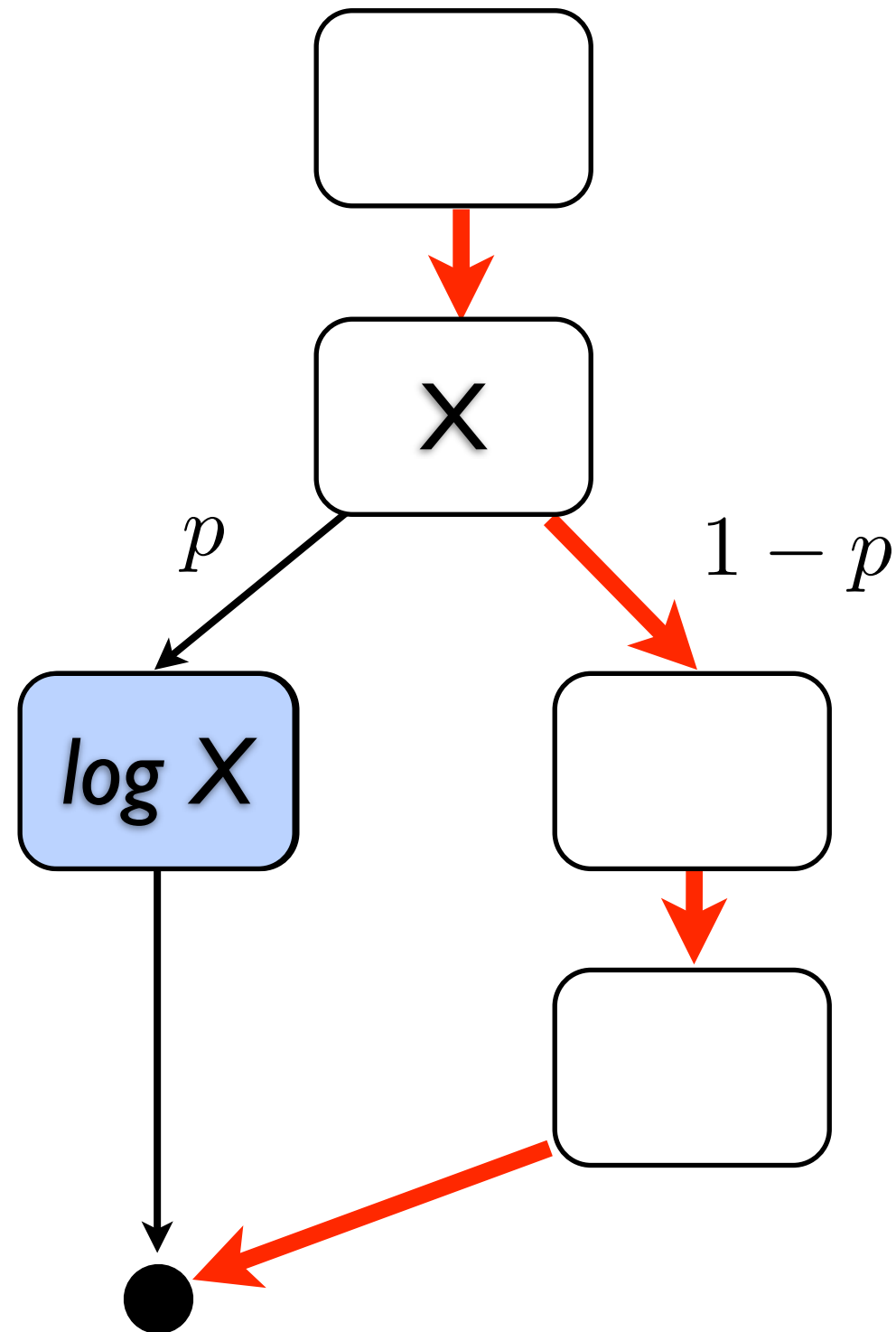


Ignore this one,
create partial trace

 WCET path

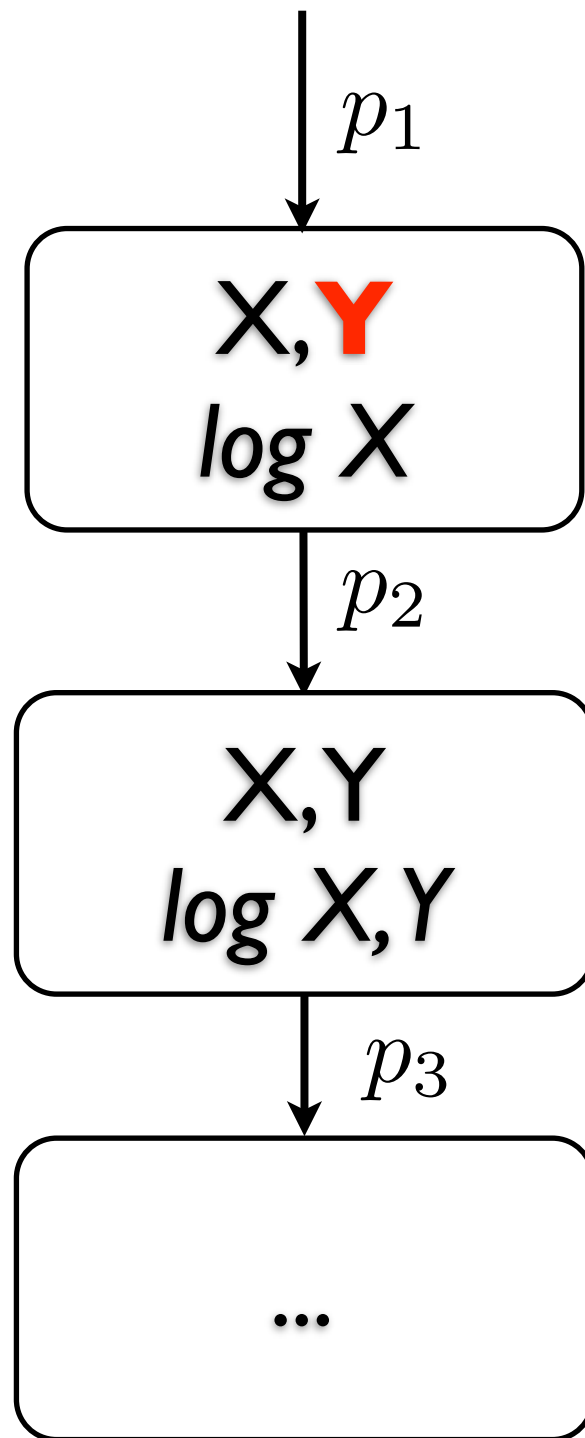
Reliability of Single Assign

Probability of capturing one assignment.



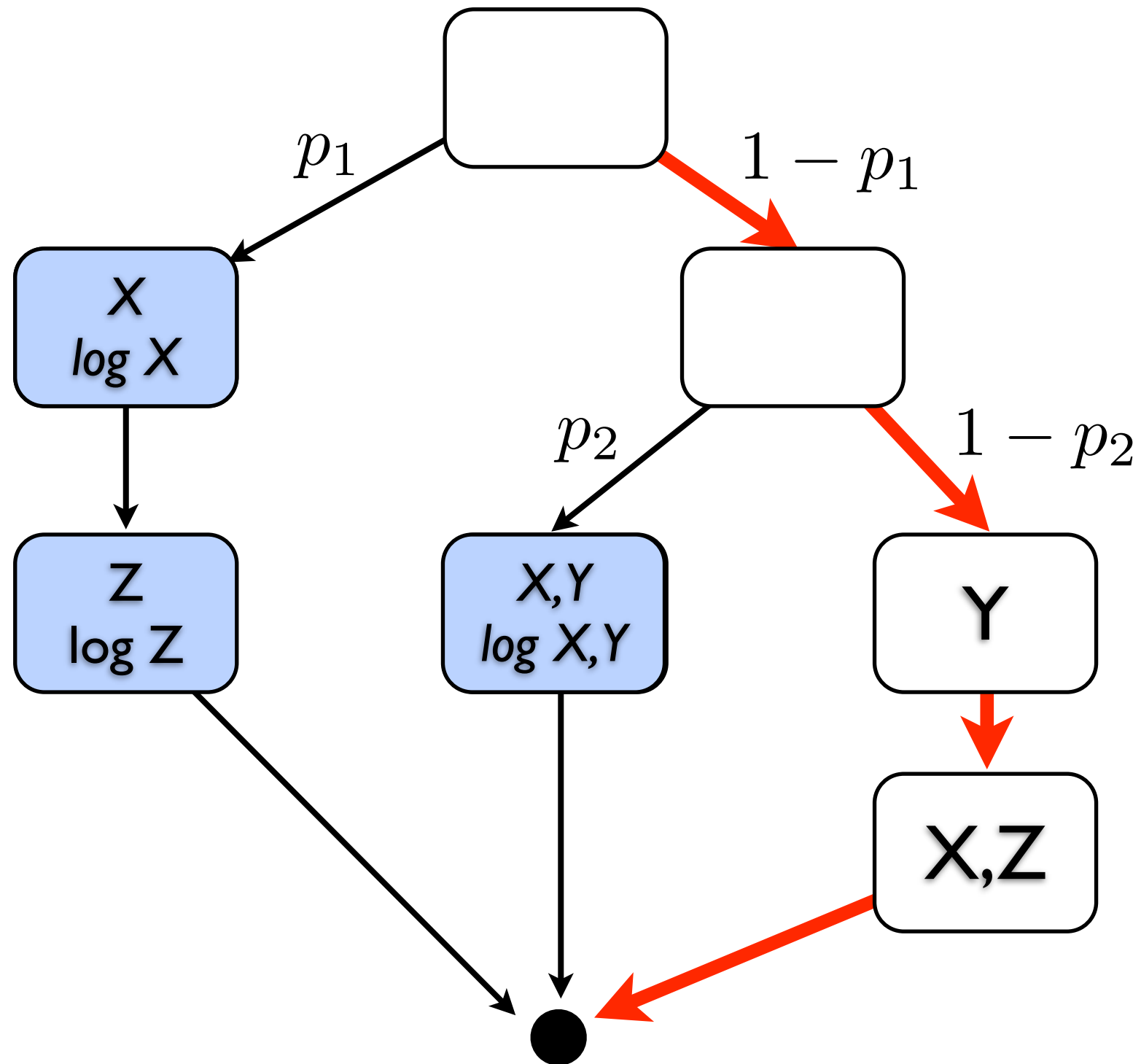
→ WCET path

Reliability of A Path



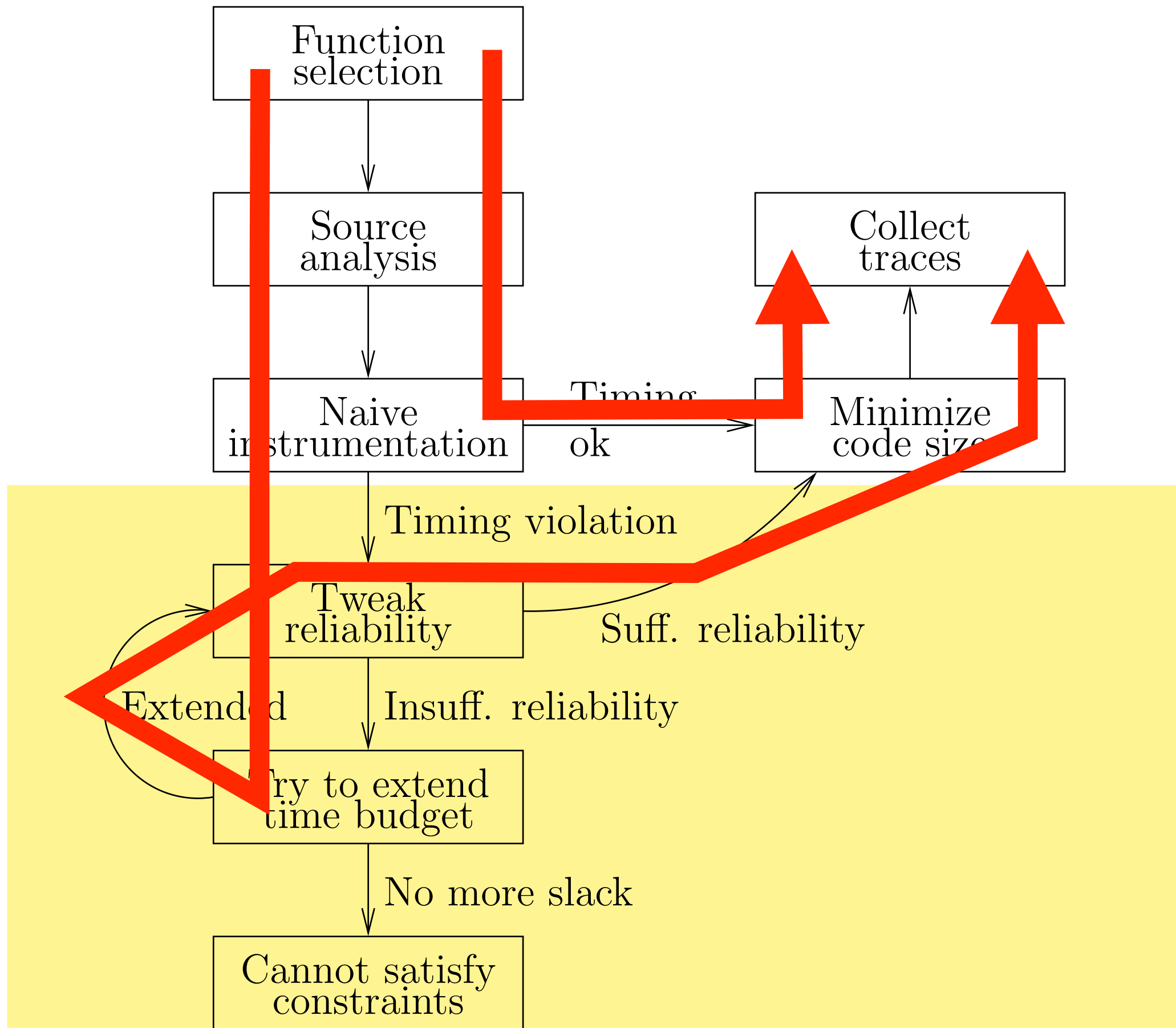
Completeness of the trace
for a particular path

Reliability of an Instrumentation



→ WCET path

Tracing Method



Instrumentation Reliability

Instead of instrumenting every read/write, maximize captures within overhead budget

- Reliability at the insertion point
- Reliability of a path
- Reliability of an instrumentation

Maximize reliability of an instrumentation

Maximal Reliability

$$\max \sum_{p \in P} \sum_{v \in p_i} p(p_i, v_i) x_i \quad (4)$$

$$\sum_{v \in p_0} p(p_0, v_i) \cdot x_i \cdot c(x_i) \leq tb - \sum_{v \in p_0} c'(v_i) \quad (5)$$

...

$$\sum_{v \in p_n} p(p_n, v_i) \cdot x_i \cdot c(x_i) \leq tb - \sum_{v \in p_n} c'(v_i)$$

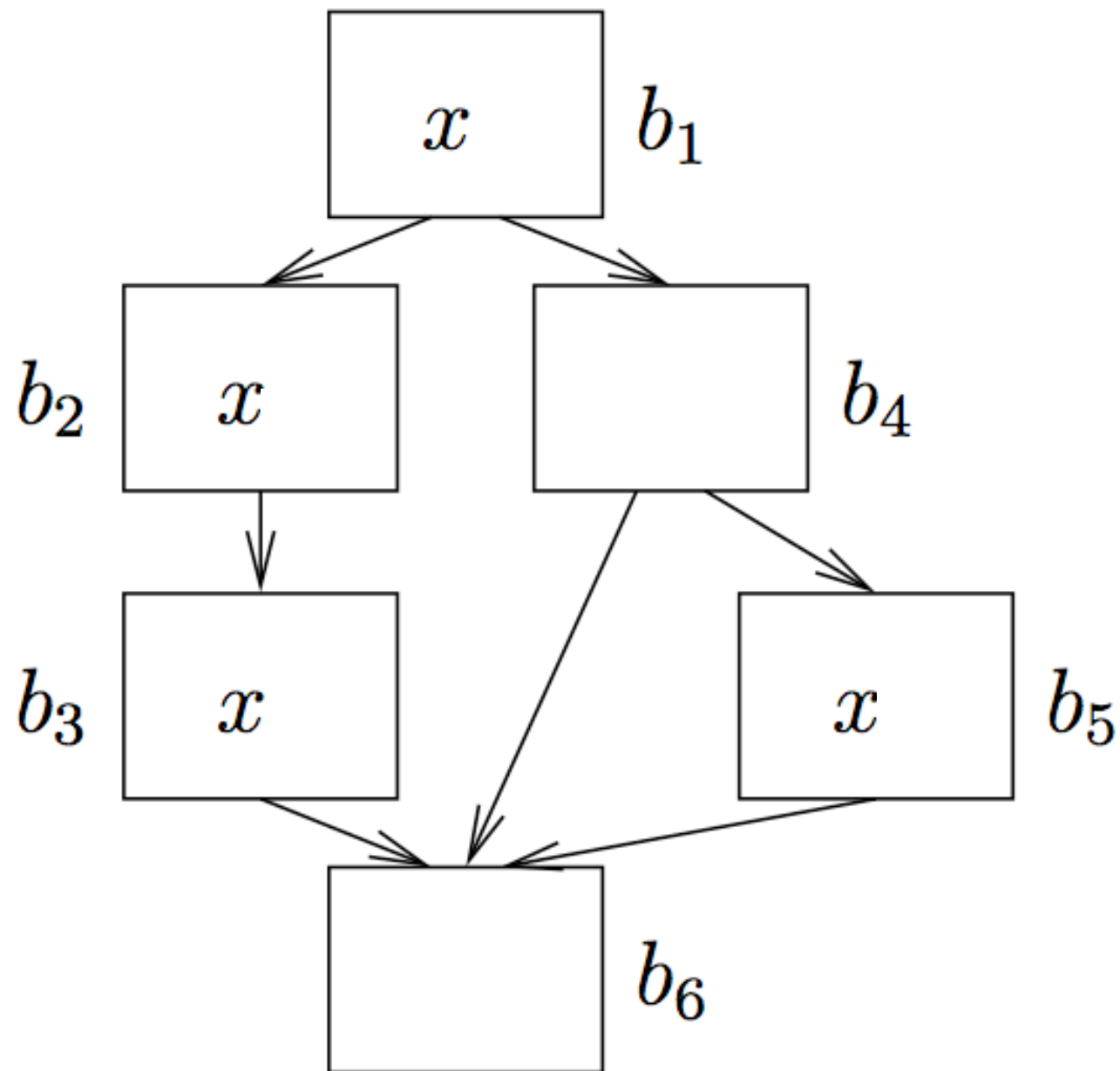
$$x_0 \leq |v_0 \cdot A| \quad (6)$$

...

$$x_n \leq |v_n \cdot A|$$

Minimize Insertion Points

Defer captures until next write



Hitting set problem

Case Study: Objectives

- Test feasibility of our approach
- Test our hypothesis of shifting execution time
- Play around and look for surprising things
 - Attainable reliability with zero overhead
 - Increase in overhead vs reliability

Case Study: OLPC

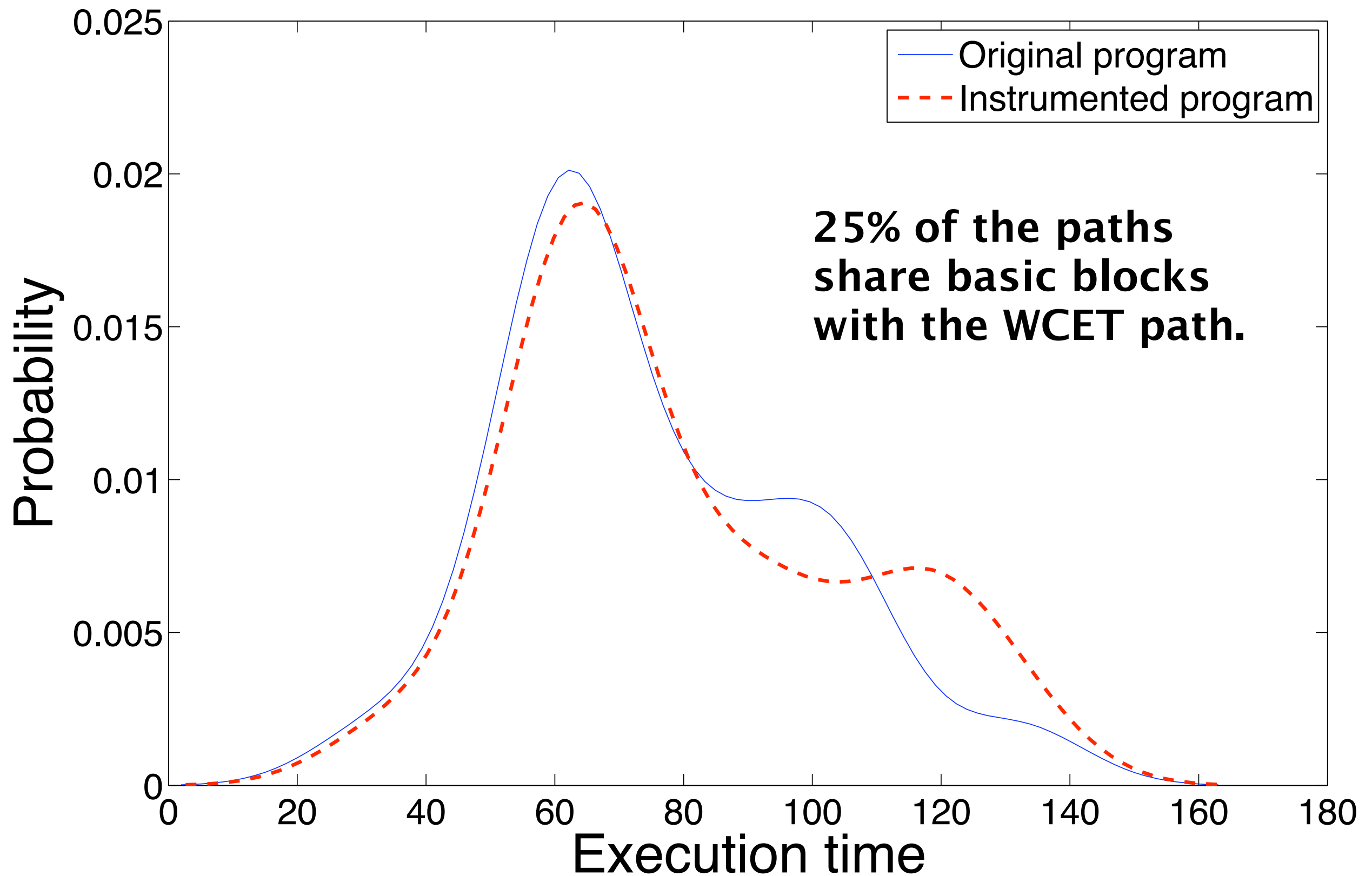


- Open source keyboard controller

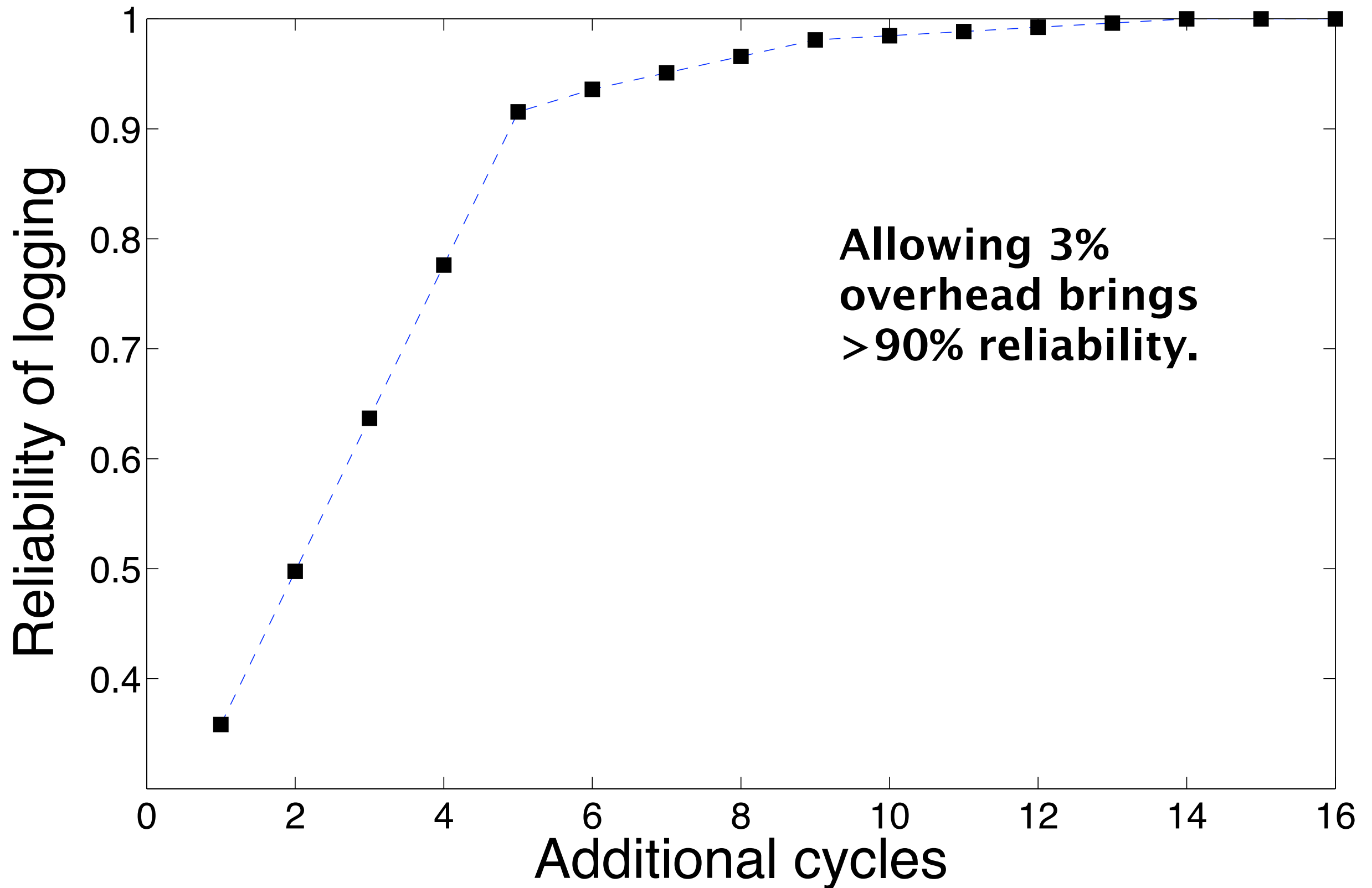
Case Study

- Function `handle_power()`
 - 42 basic blocks
 - 20 different control flows
 - mean execution time is 75 cycles
 - worst-case execution time is 132 cycles
- Built source analysis tool in OCaml
- Use ILP library in Matlab

Execution Time



Increasing the Time Budget



Tool (gen. two)

Real Time Parser

Graph Stats

Globals

```

__zero_reg__=1
main=null
__do_copy_data=null
__SREG__=0x3f
__tmp_reg__=0
__vector_4=null
__SP_H__=0x3e
__do_clear_bss=null

```

Functions

Starting Block

Ending Block

Block Code

```

sts key_press,__zero_reg__
rjmp .L4

```

Written Variables

Read Variables

```

__zero_reg__

```

Control Flow Graph (CFG) showing blocks: L4, L417, L418, L419, L420, L421, L422, L423, L424, L425, L426, L427, L428, L429, L430, L431, L432, L433, L434, L435, L436, L437, L438, L439, L440, L441, L442, L443, L444, L445, L446, L447, L448, L449, L450, L451, L452, L453, L454, L455, L456, L457, L458, L459, L460, L461, L462, L463, L464, L465, L466, L467, L468, L469, L470, L471, L472, L473, L474, L475, L476, L477, L478, L479, L480, L481, L482, L483, L484, L485, L486, L487, L488, L489, L490, L491, L492, L493, L494, L495, L496, L497, L498, L499, L500, L501, L502, L503, L504, L505, L506, L507, L508, L509, L510, L511, L512, L513, L514, L515, L516, L517, L518, L519, L520, L521, L522, L523, L524, L525, L526, L527, L528, L529, L530, L531, L532, L533, L534, L535, L536, L537, L538, L539, L540, L541, L542, L543, L544, L545, L546, L547, L548, L549, L550, L551, L552, L553, L554, L555, L556, L557, L558, L559, L560, L561, L562, L563, L564, L565, L566, L567, L568, L569, L570, L571, L572, L573, L574, L575, L576, L577, L578, L579, L580, L581, L582, L583, L584, L585, L586, L587, L588, L589, L590, L591, L592, L593, L594, L595, L596, L597, L598, L599, L600, L601, L602, L603, L604, L605, L606, L607, L608, L609, L610, L611, L612, L613, L614, L615, L616, L617, L618, L619, L620, L621, L622, L623, L624, L625, L626, L627, L628, L629, L630, L631, L632, L633, L634, L635, L636, L637, L638, L639, L640, L641, L642, L643, L644, L645, L646, L647, L648, L649, L650, L651, L652, L653, L654, L655, L656, L657, L658, L659, L660, L661, L662, L663, L664, L665, L666, L667, L668, L669, L670, L671, L672, L673, L674, L675, L676, L677, L678, L679, L680, L681, L682, L683, L684, L685, L686, L687, L688, L689, L690, L691, L692, L693, L694, L695, L696, L697, L698, L699, L700, L701, L702, L703, L704, L705, L706, L707, L708, L709, L710, L711, L712, L713, L714, L715, L716, L717, L718, L719, L720, L721, L722, L723, L724, L725, L726, L727, L728, L729, L730, L731, L732, L733, L734, L735, L736, L737, L738, L739, L740, L741, L742, L743, L744, L745, L746, L747, L748, L749, L750, L751, L752, L753, L754, L755, L756, L757, L758, L759, L760, L761, L762, L763, L764, L765, L766, L767, L768, L769, L770, L771, L772, L773, L774, L775, L776, L777, L778, L779, L780, L781, L782, L783, L784, L785, L786, L787, L788, L789, L790, L791, L792, L793, L794, L795, L796, L797, L798, L799, L800, L801, L802, L803, L804, L805, L806, L807, L808, L809, L810, L811, L812, L813, L814, L815, L816, L817, L818, L819, L820, L821, L822, L823, L824, L825, L826, L827, L828, L829, L830, L831, L832, L833, L834, L835, L836, L837, L838, L839, L840, L841, L842, L843, L844, L845, L846, L847, L848, L849, L850, L851, L852, L853, L854, L855, L856, L857, L858, L859, L860, L861, L862, L863, L864, L865, L866, L867, L868, L869, L870, L871, L872, L873, L874, L875, L876, L877, L878, L879, L880, L881, L882, L883, L884, L885, L886, L887, L888, L889, L890, L891, L892, L893, L894, L895, L896, L897, L898, L899, L900, L901, L902, L903, L904, L905, L906, L907, L908, L909, L910, L911, L912, L913, L914, L915, L916, L917, L918, L919, L920, L921, L922, L923, L924, L925, L926, L927, L928, L929, L930, L931, L932, L933, L934, L935, L936, L937, L938, L939, L940, L941, L942, L943, L944, L945, L946, L947, L948, L949, L950, L951, L952, L953, L954, L955, L956, L957, L958, L959, L960, L961, L962, L963, L964, L965, L966, L967, L968, L969, L970, L971, L972, L973, L974, L975, L976, L977, L978, L979, L980, L981, L982, L983, L984, L985, L986, L987, L988, L989, L990, L991, L992, L993, L994, L995, L996, L997, L998, L999, L1000.

Register Group Stats

Register	Read Count	Write Count
Status Regs	2	2
Stack	9	9
TREG	0	0
SRAM	0	6
IO Regs	3	7

gcc => assembly => analyze =>
instrument => compile => deploy

Future Work

- Extend to multiprogramming environments
- Refine insertion algorithm wrt interaction between minimization and reliability
- Open source Eclipse plugin

Conclusions

- Debugging is a real problem
- Tracing is a common, so far ad hoc, solution
- First steps towards automated trace generation for real-time programs
 - Optimization problem to maximize trace value.
 - Reduction for minimizing insertion points.
 - Equations for calculating the buffer size.

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