Synchronisation Synthesis for Concurrent Programs

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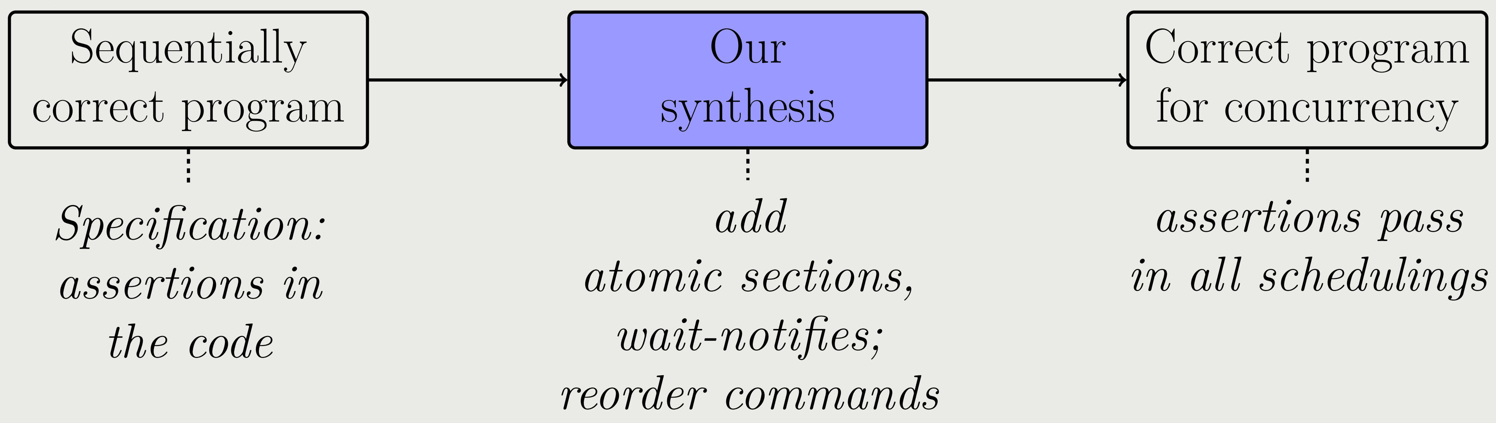
Introduction: Concurrency bugs

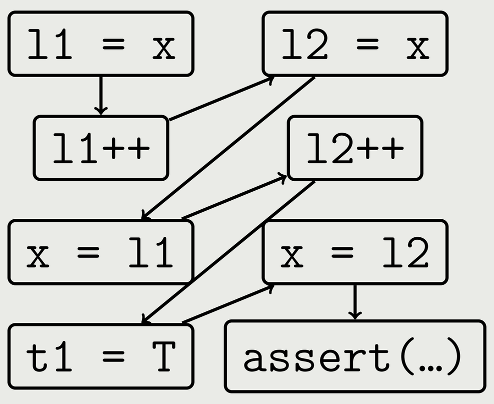
- Concurrency bugs are hard to find and fix
- We attempt to fix them automatically using synthesis
- **Specification:**



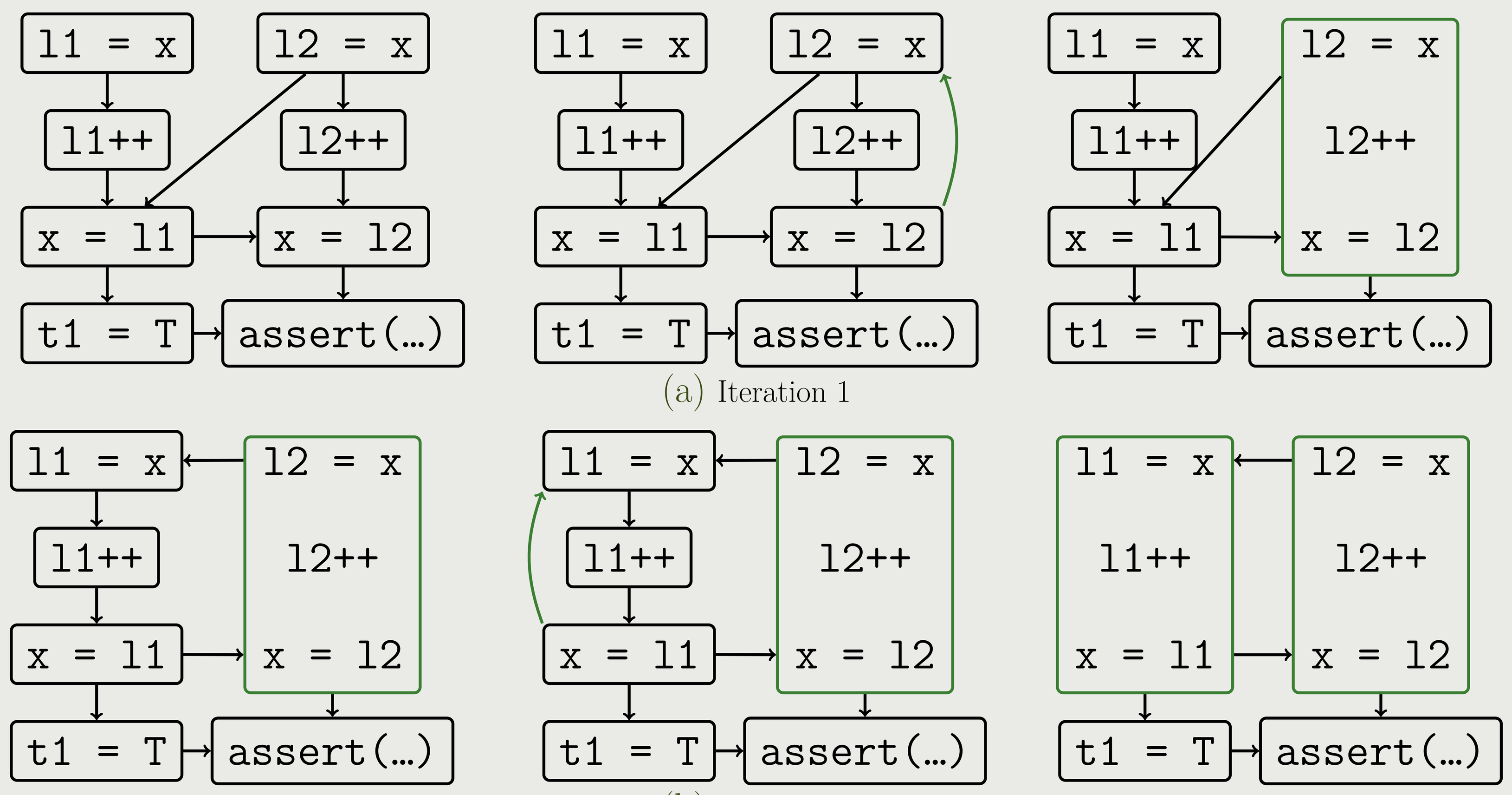
Atomic sections example

- This example requires two atomic sections to be fixed
- With a linear trace we cannot infer where to place atomic sections

```
init: x = 0; t1 = F
thread1      thread2
A: l1 = x    1: l2 = x
B: l1++      2: l2++
C: x = l1    3: x = l2
D: t1 = T    4: assert(¬t1∨x==2)
```



- Using a happens-before relationship we can infer atomic sections after two iterations
  - An atomic section is denoted by a loop inside a thread (it is created by adding an edge)

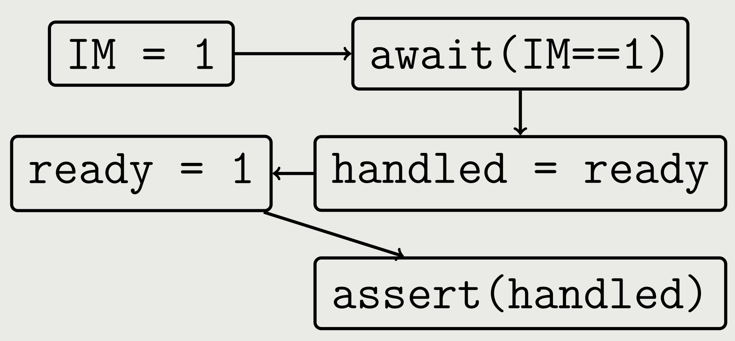


(a) Iteration 1

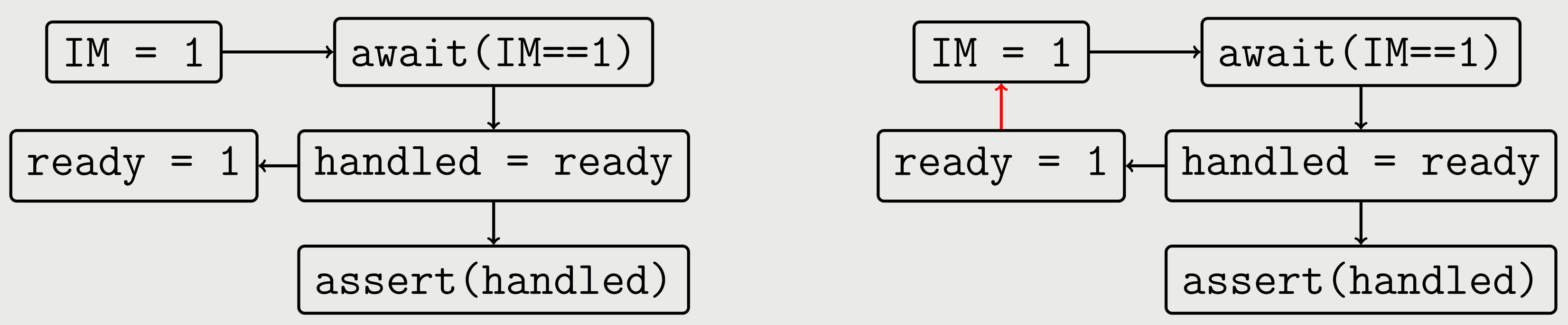
(b) Iteration 2

Reordering example

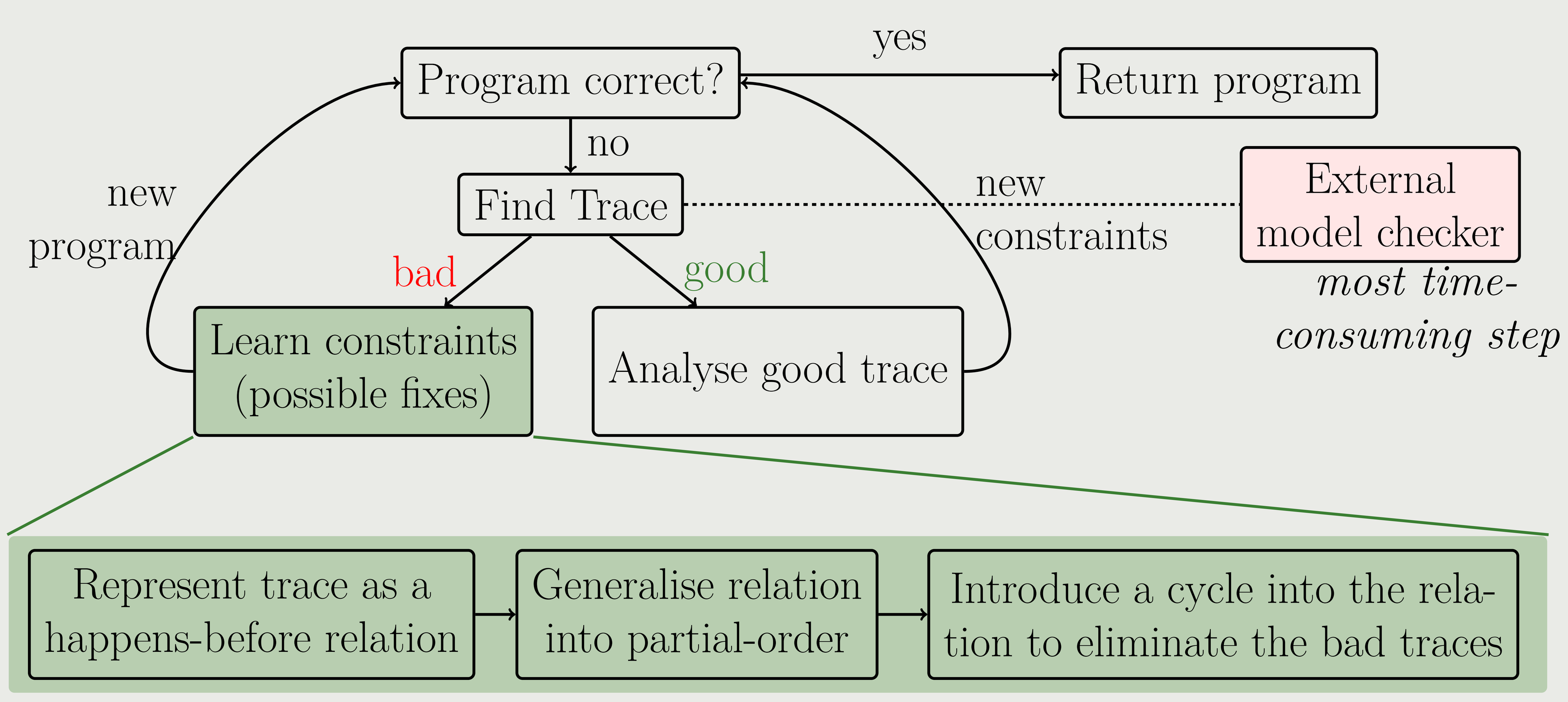
```
init: IntrMask=0; ready=0; handled=0
init_thread       intr_thread
M: IntrMask = 1   R: await(IntrMask==1)
N: ready = 1      S: handled = ready
                  T: assert(handled)
```



- We remove edges from the partial order if M; N ≡ N; M
  - If such an edge is readded to create a cycle it means the two corresponding statements will be swapped in the program



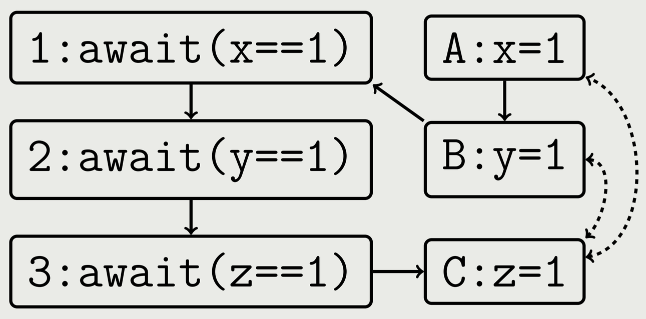
Synthesis algorithm outline



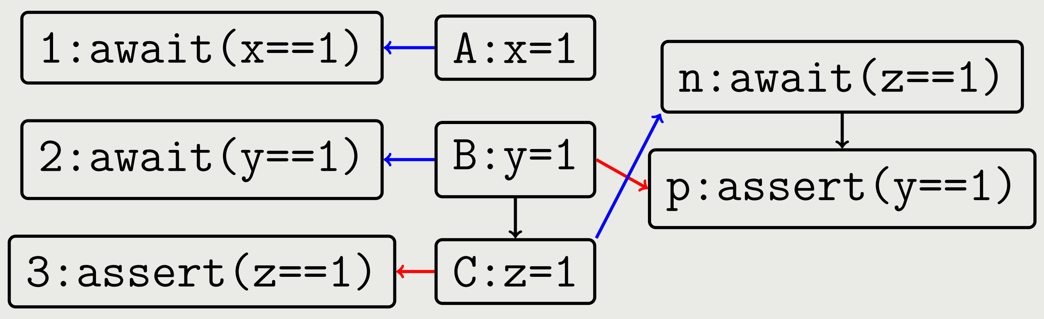
Preventing regressions by using good traces

- Reordering can cause regressions
  - By analysing a good trace we can identify possible regressions before reordering instructions

```
init: x = 0; y = 0; z = 0
thread1           thread2   thread3
1: await(x==1)    A: x=1    n: await(z==1)
2: await(y==1)    B: y=1    p: assert(y==1)
3: assert(z==1)   C: z=1
```



- A;B;1;2;3 causes assertion 3 to fail
- 2 possible fixes: swap B ↔ C or swap A ↔ C
- Swapping B ↔ C can lead to assertion p failing



- We analyse good trace A;B;C;1;2;3;n;p
- Blue edges indicate data-flow dependencies of awaits, red of asserts
- We learn not to reorder B;C and n;p to protect the data-flow into assertion p
- After good trace analysis only the correct fix A ↔ C remains

Conclusion

- We consider reorderings as fixes
- We generalise the counter-example trace to capture the cause of the error
- We pervent regressions by analysing good traces

Recent: Better trace generalisation

- Trace generalisation is crucial to the success of the synthesis
- Trace generalisation should capture the core of the bug
- Idea: Represent traces as a Boolean formula over happens-before constraints

```
global: x, withdrawal, deposit, balance, deposited, withdrawn
init: x = balance; deposited = 0; withdrawn = 0

π:
thread_withdraw:
localvars: temp
W1: temp = balance
W2: balance = temp - withdrawal
W3: withdrawn = 1

thread_deposit:
localvars: temp
D1: temp = balance
D2: balance = temp + deposit
D3: deposited = 1

thread_checkresult:
C1: assume (deposited == 1 ∧ withdrawn == 1)
C2: assert (balance == x + deposit - withdrawal)
```

Original Trace: $\pi = W_1, D_1, W_2, W_3, D_2, D_3, C_1, C_2$

Representation of bad interleavings of π:

$\mathcal{N}^b_\pi = hb(W_1, D_2) \wedge hb(D_1, W_2)$

Representation of good interleavings of π:

$\mathcal{N}^g_\pi = hb(D_2, W_1) \vee hb(W_2, D_1)$

- We introduce rewrite rules on $\mathcal{N}^g_\pi$ for synthesis, e.g.

$$\frac{hb(X_j, Y_k) \vee hb(Y_\ell, X_i) \vee \psi \quad i \leq j \quad k \leq \ell}{lock(X_{[i,j]}, Y_{[k,\ell]}) \vee \psi}\ \text{ADD.LOCK}$$

The ADD.LOCK rewriting rule yields $lock(W_{[1,2]}, D_{[1,2]})$

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