Awaiting for Godot: Stateless Model Checking that Avoids Executions where Nothing Happens

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Contributions

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  Eliminate *pure* loop iterations by inserting `await` statements

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- *Partial Loop Purity Elimination*:
  Eliminate *pure* loop iterations by inserting `await` statements
- Optimal-DPOR-Await:
  Efficient SMC algorithm supporting `await`s and independent fetch-and-adds
- Implementation in Nidhugg

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Exhaustively test terminating concurrent program with fixed input

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Exhaustively test terminating concurrent program with fixed input

- How: Systematically explore all thread schedulings
- Problem: Combinatorial explosion
- Solution: *Dynamic Partial-Order Reduction (DPOR)* [Flanagan & Godefroid 2005] explores only the orderings of dependent events
- Optimal DPOR [Abdulla et al. 2014, 2017] never visits two equivalent executions

Termination in Stateless Model Checking

- Problem: The programs must terminate

Example: Spinloops

p	q

`y := 42;`
`x := 1`
	`do  a := x`
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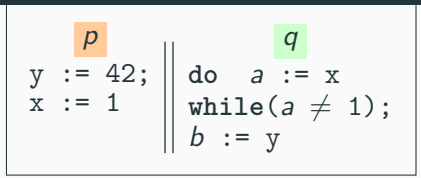

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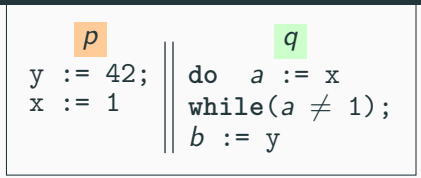

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- Observation: Many programs are non-terminating due to *pure* loop iterations
- Idea: Avoid exploring executions containing pure loop iterations

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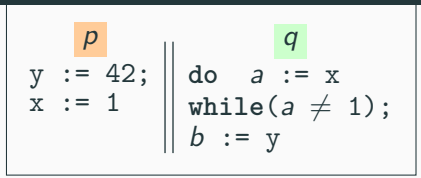

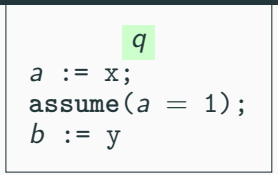

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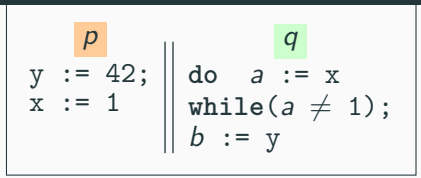

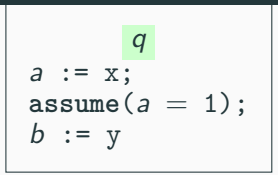

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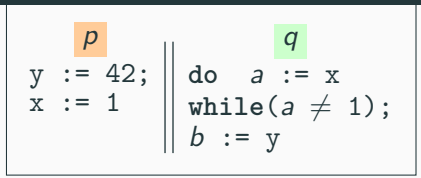

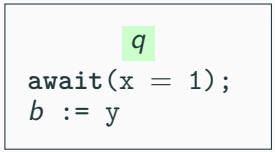

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Example: Spinloops

```
p                    q
y := 42;  ||  do  a := x
x := 1    ||  while(a ≠ 1);
          ||  b := y
```

```
q
await(x = 1);
b := y
```

p : y := 42
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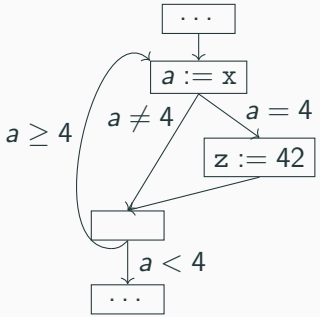

In SSA form

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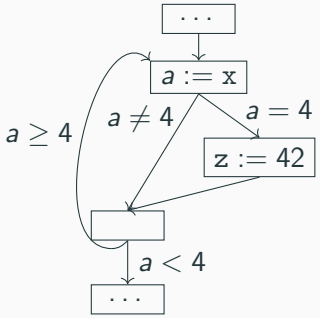

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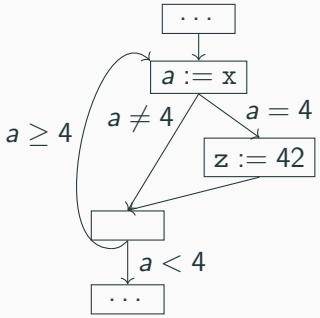

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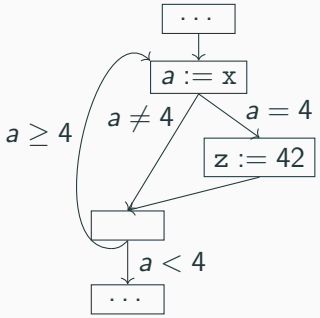

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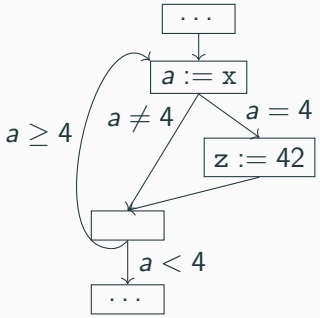

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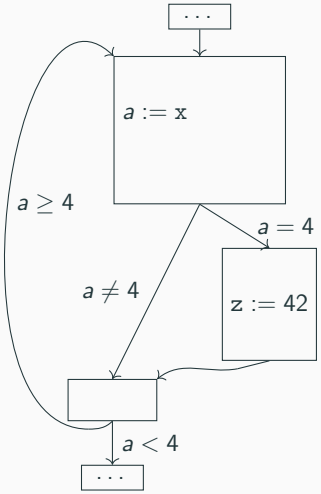

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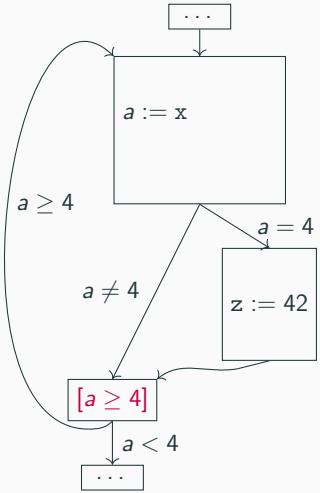

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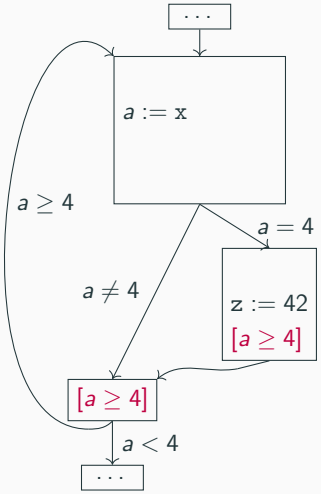

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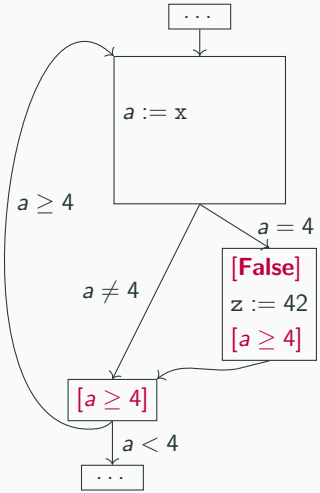

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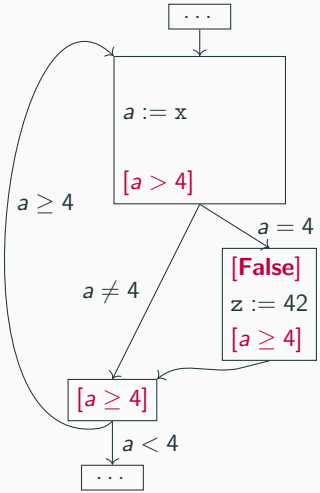

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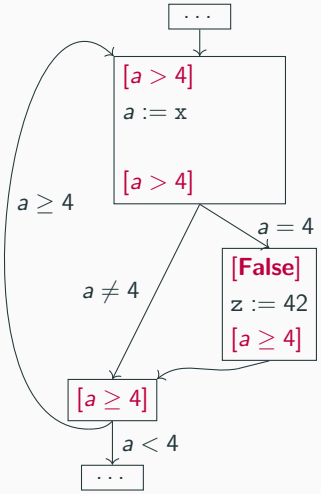

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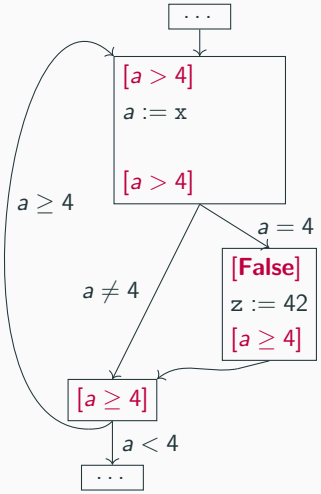

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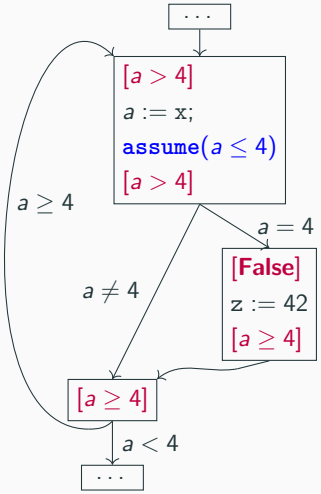

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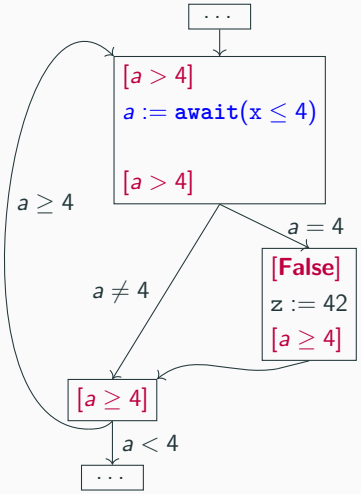

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A new optimal DPOR algorithm

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And an implementation in NIDHUGG, with PLP and IFAA

- Without IFAA: $n!$ executions
- With IFAA: 1 execution

Evaluation

	GenMC	Nidhugg
Benchmark		

Evaluation

	GenMC	Nidhugg
Benchmark	Baseline	Baseline

Evaluation

	GenMC		Nidhugg
Benchmark	Baseline	Saver	Baseline

Evaluation

	GenMC		Nidhugg	
Benchmark	Baseline	Saver	Baseline	PLP

Evaluation

	GenMC		Nidhugg		
Benchmark	Baseline	Saver	Baseline	PLP	PLP+Await

Evaluation

	GenMC		Nidhugg			
Benchmark	Baseline	Saver	Baseline	PLP	PLP+Await	...+IFAA

Evaluation

	GenMC		Nidhugg			
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qspinlock(2)	6+2	6+2	6+2	6+2	6+2	6+2
qspinlock(3)	564	564	564	564	564	564

Evaluation

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Benchmark	Baseline	Saver	Baseline	PLP	PLP+Await	...+IFAA
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qspinlock(3)	564	564	564	564	564	564
mutex(2)	12+2	12+2	12+2	12+2	12	10
mutex(3)	9486+1236	6582+1188	9486+1236	6582+1188	6582+336	3618+312

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Benchmark	Baseline	Saver	Baseline	PLP	PLP+Await	...+IFAA
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qspinlock(3)	564	564	564	564	564	564
mutex(2)	12+2	12+2	12+2	12+2	12	10
mutex(3)	9486+1236	6582+1188	9486+1236	6582+1188	6582+336	3618+312
seqlock(3)	147+230	9+83	147+230	9+83	9+36	9+36
seqlock(4)	87980+105123	88+2805	87980+104583	88+2769	88+729	88+729

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qspinlock(3)	564	564	564	564	564	564
mutex(2)	12+2	12+2	12+2	12+2	12	10
mutex(3)	9486+1236	6582+1188	9486+1236	6582+1188	6582+336	3618+312
seqlock(3)	147+230	9+83	147+230	9+83	9+36	9+36
seqlock(4)	87980+105123	88+2805	87980+104583	88+2769	88+729	88+729
mpmc-queue(3)	11206+11612	166+987	11206+8188	166+840	166+517	76+421
mpmc-queue(4)		39706+1277783		39706+1123234	39706+360426	5410+114208

Evaluation

	GenMC		Nidhugg			
Benchmark	Baseline	Saver	Baseline	PLP	PLP+Await	...+IFAA
qspinlock(2)	6+2	6+2	6+2	6+2	6+2	6+2
qspinlock(3)	564	564	564	564	564	564
mutex(2)	12+2	12+2	12+2	12+2	12	10
mutex(3)	9486+1236	6582+1188	9486+1236	6582+1188	6582+336	3618+312
seqlock(3)	147+230	9+83	147+230	9+83	9+36	9+36
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mpmc-queue(3)	11206+11612	166+987	11206+8188	166+840	166+517	76+421
mpmc-queue(4)		39706+1277783		39706+1123234	39706+360426	5410+114208
treiber-stack(3)	426	274+80	426	274+80	274+60	274+60
treiber-stack(4)	1546168+9216	250088+167916	1546168+9216	250088+167916	250088+90896	250088+90896

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mpmc-queue(4)	🐻	39706+1277783	🐻	39706+1123234	39706+360426	5410+114208
treiber-stack(3)	426	274+80	426	274+80	274+60	274+60
treiber-stack(4)	1546168+9216	250088+167916	1546168+9216	250088+167916	250088+90896	250088+90896
sortnet(4)	†	1+728	1+312	1+312	1	1
sortnet(5)	†	1+15231	1+4517	1+4517	1	1
sortnet(6)	†	1+163292	1+38285	1+38285	1	1

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An attempt at a lock-free stack

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- Nidhugg/...+IFAA:
  - finds it in 8 min, 2+2453474 executions
  - exhausts the search space in 24 mins, 5772+8521721 executions

Results on SafeStack

	GenMC		Nidhugg			
Benchmark	Baseline	Saver	Baseline	PLP	PLP+Await	...+IFAA

Results on SafeStack

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Benchmark	Baseline	Saver	Baseline	PLP	PLP+Await	...+IFAA
safestack-21(2)	119+6	119+6	119+6	34+2	34+1	19+1

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Benchmark	Baseline	Saver	Baseline	PLP	PLP+Await	...+IFAA
safestack-21(2)	119+6	119+6	119+6	34+2	34+1	19+1
safestack-31(2)	928+107	928+107	928+107	103+27	103+25	56+25

Results on SafeStack

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Benchmark	Baseline	Saver	Baseline	PLP	PLP+Await	...+IFAA
safestack-21(2)	119+6	119+6	119+6	34+2	34+1	19+1
safestack-31(2)	928+107	928+107	928+107	103+27	103+25	56+25
safestack-32(2)	7189+296	7189+296	7189+296	1073+27	1073+12	463+12

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safestack-32(2)	7189+296	7189+296	7189+296	1073+27	1073+12	463+12
safestack-33(2)	121334+12652	121334+12652	121334+12652	6434+1636	6434+1584	2600+1160

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safestack-32(2)	7189+296	7189+296	7189+296	1073+27	1073+12	463+12
safestack-33(2)	121334+12652	121334+12652	121334+12652	6434+1636	6434+1584	2600+1160
safestack-211(3)	1267120+325932	995224+325932	1259280+324382	2690+1126	2690+928	962+686

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safestack-211(3)	1267120+325932	995224+325932	1259280+324382	2690+1126	2690+928	962+686
safestack-311(3)	0+286818740	0+275399108		0+26536	0+24078	0+14960

Results on SafeStack

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Benchmark	Baseline	Saver	Baseline	PLP	PLP+Await	...+IFAA
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safestack-31(2)	928+107	928+107	928+107	103+27	103+25	56+25
safestack-32(2)	7189+296	7189+296	7189+296	1073+27	1073+12	463+12
safestack-33(2)	121334+12652	121334+12652	121334+12652	6434+1636	6434+1584	2600+1160
safestack-211(3)	1267120+325932	995224+325932	1259280+324382	2690+1126	2690+928	962+686
safestack-311(3)	0+286818740	0+275399108		0+26536	0+24078	0+14960
safestack-321(3)				906529+388117	906529+331337	288057+216830

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Available today in Nidhugg: `https://github.com/nidhugg/nidhugg`

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Thank you for listening!