Dynamic Partial Order Reductions for Spinloops

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[2]The University of British Columbia

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$\rightsquigarrow$ loops have to be bounded

Bounding is expensive

We want larger bounds to be confident that the program is correct

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Consider a **reader-writer lock** implementation

$\rightsquigarrow$ let's try to verify it using a state-of-the-art DPOR implementation

	$b = 1$	$b = 2$	$b = 3$	$b = 4$
linuxrwlocks	0.02s	26.98s	1366.67s	⏱

Verification time using GenMC (30m timeout)

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DPOR explores the possibility of each loop failing $0, 1, \ldots, b - 1$ times

Solution

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This work

SAVER: Spinloop-Aware Verifier

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$[x = 0, z = ?]$

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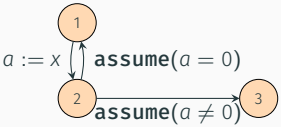

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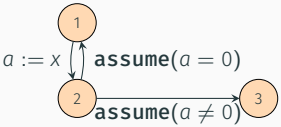

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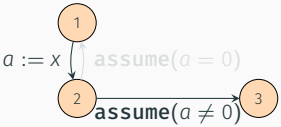

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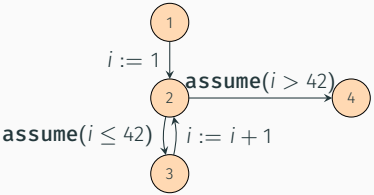

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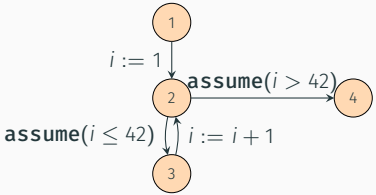

Cannot employ spin-assume: modifies variable live at header

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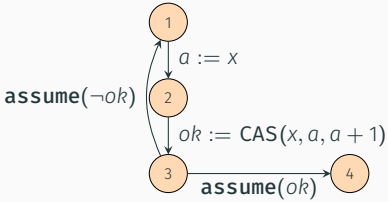

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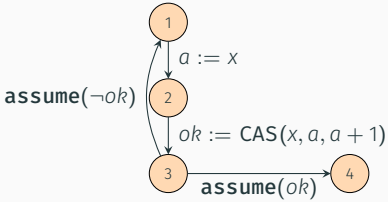

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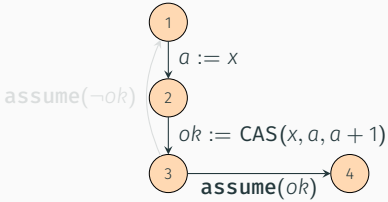

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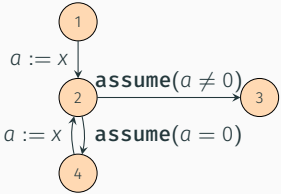

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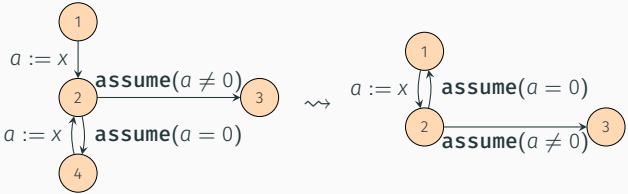

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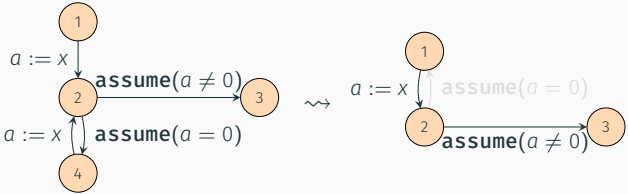

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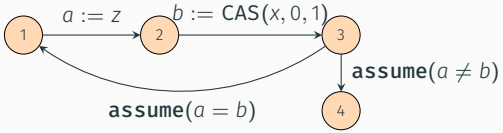

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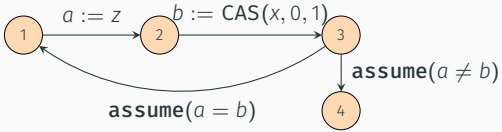

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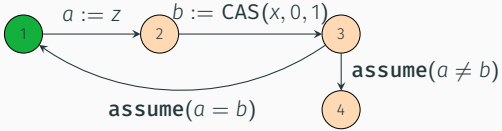

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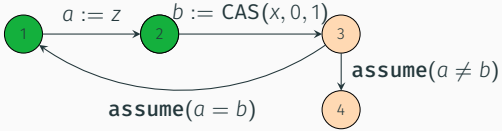

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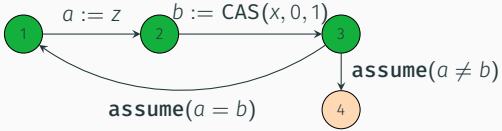

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n := new_node() // heap mem
n.value := 42
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    s := stack
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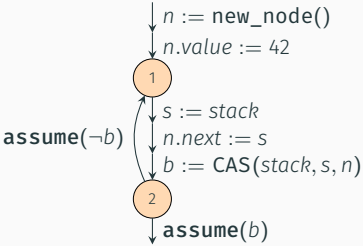

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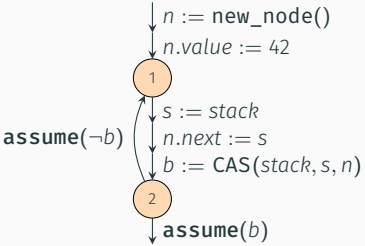

Yes, as long as the stores are not visible to other threads!

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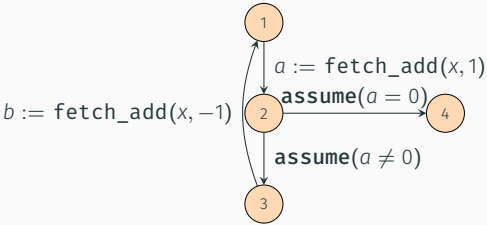

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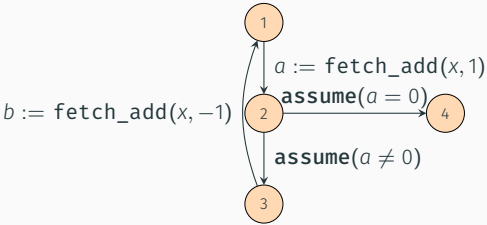

Employ the ZNE-assume transformation

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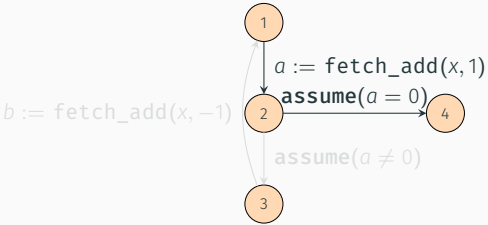

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while $(true)$ $\quad a := \texttt{fetch\_add}(x, 1)$ $\quad$ **if** $(a = 42)$ **break** $\quad \texttt{fetch\_add}(x, -1)$	$b := x$ $c := x$

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while $(true)$ $\quad a := \texttt{fetch\_add}(x, 1)$ $\quad$ **if** $(a = 42)$ **break** $\quad \texttt{fetch\_add}(x, -1)$	$b := x$ // 1 $c := x$ // 0

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$[x = 0]$

while (true)	
$a :=$ `fetch_add`$(x, 1)$	$b := x$ // 1
if $(a = 42)$ **break**	$c := x$ // 1
`fetch_add`$(x, -1)$	

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Need to check ZNE-assume validity dynamically!

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```

SAVER: Spinloop-Aware Verifier

Effect-free

$[x = 0]$

```
do
  a := x
while (a = 0)
```

- Spin-assume
- Bisimilarity/loop rotation

Potentially-effect-free

$[x = 0, z = ?]$

```
do
  a := z
  b := CAS(x, 0, 1)
while (a = b)
```

- Dynamic spin-assume

Zero-net-effect

$[x = y = 0]$

```
while (true)
    a := fetch_add(x, 1)
    if (a = 0) break
    fetch_add(x, −1)
// critical section
fetch_add(x, −1)
```

- ZNE-assume
- Dynamic validity checks

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```
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while (true)
    a := fetch_add(x, 1)
    if (a = 0) break
    fetch_add(x, −1)
// critical section
fetch_add(x, −1)
```

- ZNE-assume
- Dynamic validity checks

We can apply a different transformation to each backedge!

Putting everything together: Michael-Scott queue

$[head = \ldots, tail = \ldots]$

```
success := false
while (¬success)
    h := head
    t := tail
    n := next[h]
    h' := head
    if (h ≠ h') continue
    if (h = t)
        if (n) break
        CAS(tail, t, n)
    else
        success := CAS(head, h, n)
```

Putting everything together: Michael-Scott queue

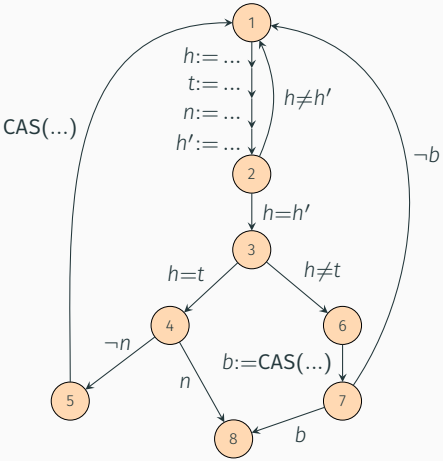
$[head = \ldots, tail = \ldots]$

```
while (true)  // loop rotation
    h := head
    t := tail
    n := next[h]
    h' := head
    if (h ≠ h') continue
    if (h = t)
        if (n) break
        CAS(tail, t, n)
    else
        b := CAS(head, h, n)
        if (b) break
```

Putting everything together: Michael-Scott queue

$[head = \ldots, tail = \ldots]$

```
while (true)  //loop rotation
    h := head
    t := tail
    n := next[h]
    h' := head
    if (h ≠ h') continue
    if (h = t)
        if (n) break
        CAS(tail, t, n)
    else
        b := CAS(head, h, n)
        if (b) break
```



Putting everything together: Michael-Scott queue

$[head = \ldots, tail = \ldots]$

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while (true)  // loop rotation
    h := head
    t := tail
    n := next[h]
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    if (h = t)
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        CAS(tail, t, n)
    else
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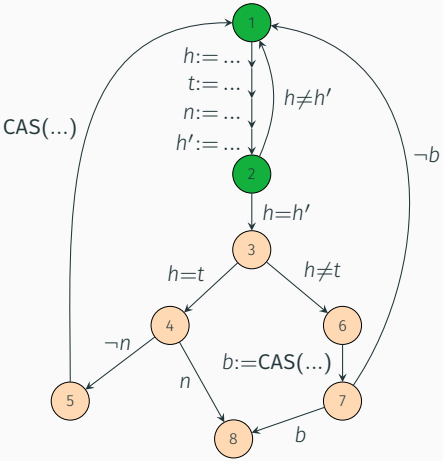
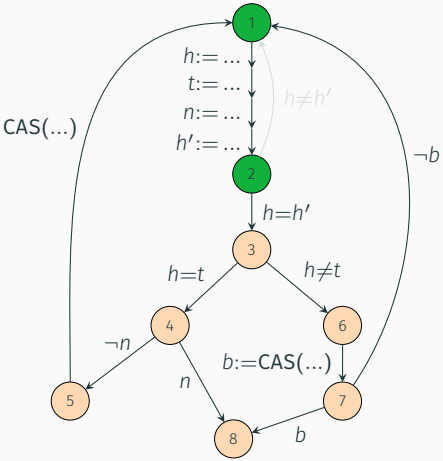


Putting everything together: Michael-Scott queue

$[head = \ldots, tail = \ldots]$

```
while (true)  // loop rotation
    h := head
    t := tail
    n := next[h]
    h' := head
    if (h ≠ h') continue // SA
    if (h = t)
        if (n) break
        CAS(tail, t, n)
    else
        b := CAS(head, h, n)
        if (b) break
```



Putting everything together: Michael-Scott queue

$[head = \ldots, tail = \ldots]$

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while (true)  // loop rotation
    h := head
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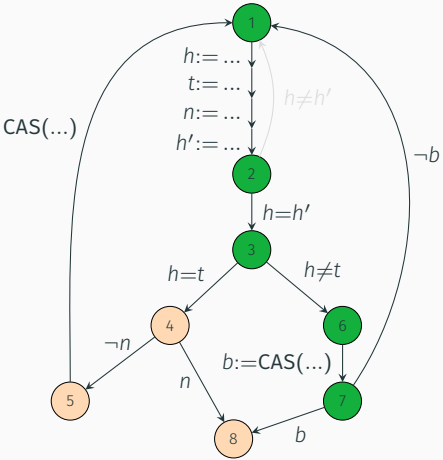
    if (h = t)
        if (n)  break
        CAS(tail, t, n)
    else
        b := CAS(head, h, n)
        if (b)  break
```



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$[head = \ldots, tail = \ldots]$

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while (true)  // loop rotation
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    if (h = t)
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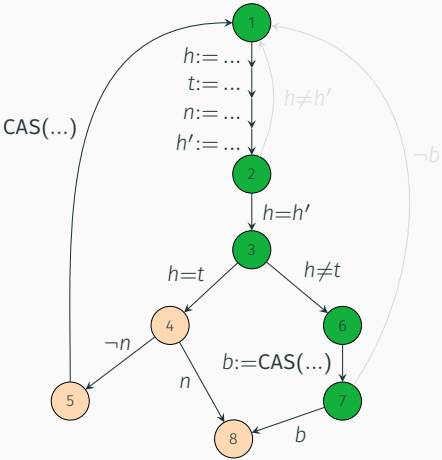
        CAS(tail, t, n)
    else
        b := CAS(head, h, n)
        if (b)  break // SA
```



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    else
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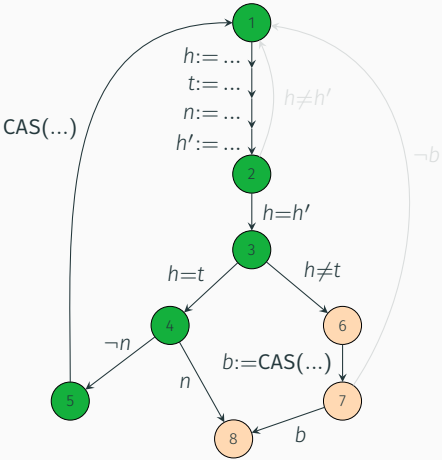
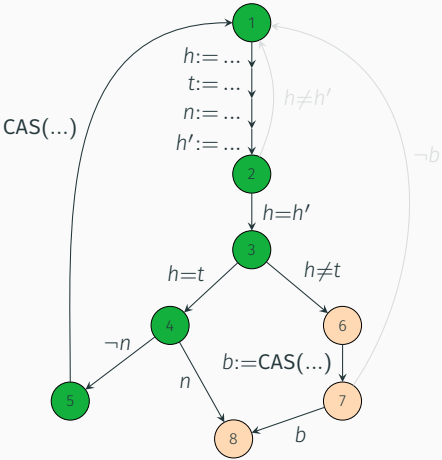
        if (b)  break // SA
```



Putting everything together: Michael-Scott queue

$[head = \ldots, tail = \ldots]$

```
while (true)  // loop rotation
    h := head
    t := tail
    n := next[h]
    h' := head
    if (h ≠ h')  continue // SA
    if (h = t)
        if (n)  break
        CAS(tail, t, n) // DSA
    else
        b := CAS(head, h, n)
        if (b)  break // SA
```



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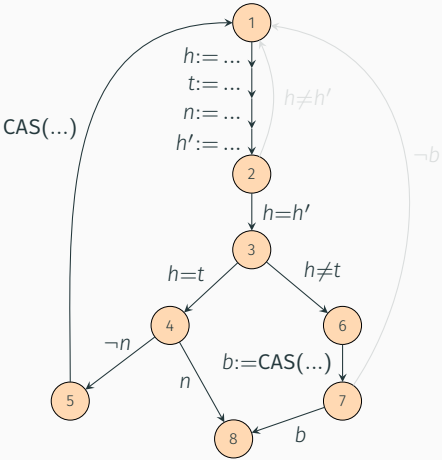
```



Results

Realistic benchmarks

	GenMC$_{\setminus S}$	GenMC	Saver		
	Execs	*Execs*	*Execs*	*Time*	*Trans*
linuxrwlocks(3)	14059037	38033	24	.04	B, S, Z
linuxrwlocks(4)	⏰	⏰	1060	.36	B, S, Z
chase-lev(5)	17367	17367	3835	.20	S
chase-lev(6)	778581	778581	41055	2.39	S
treiber-stack(3)	426	426	18	.10	S, D
treiber-stack(4)	1546168	1546168	484	.61	S, D
ttaslock(3)	11031	11031	162	.10	S, D
ttaslock(4)	⏰	⏰	20760	2.46	S, D
twalock(3)	1338	1338	96	.10	S
twalock(4)	1018872	1018872	6144	.72	S
ms-queue(3)	1389	1389	75	.09	L, S, D
ms-queue(4)	⏰	⏰	10662	28.13	L, S, D

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ms-queue(3)	1389	1389	75	.09	L, S, D
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Conclusion

SAVER: a Spinloop-Aware Verifier

- novel extensions to DPOR
  - spin-assume
  - bisimilarity/loop rotation
  - dynamic-spin-assume
  - ZNE-assume
- works for a variety of memory models
- exponentially fewer executions than state-of-the-art

`https://github.com/MPI-SWS/genmc`