Behaviour-Oriented Concurrency

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https://github.com/Foreverhighness/boc-talk

Links

Behaviour-Oriented Concurrency Paper

Basic C# implementation

Core C++ implementation

Presentation video

Supplementary

KAIST CS431: Concurrent Programming

Concurrency

Parallelism

- Thread
- Task
- Coroutines
- Async
- …

Coordination

- Promises
- Locks
- Condition variables
- Transactions
- …

Concurrency

Parallelism

- Thread
- Task
- Coroutines
- Async
- ...

Coordination

- Promises
- Locks
- Condition variables
- Transactions
- ...

$$\text{spawn}(A \xrightarrow{\text{transfer 100}} B\ ) \qquad \text{spawn}(B \xrightarrow{\text{transfer 100}} C)$$

$$\text{spawn}(C \xrightarrow{\text{transfer 100}} D\ ) \qquad \text{spawn}(D \xrightarrow{\text{transfer 100}} A)$$

Goal

- Isolation
- Parallelism
- Deadlock Freedom
- Causal Ordering

$$\text{spawn}(A \xrightarrow{\text{transfer 100}} B\ ) \qquad \text{spawn}(B \xrightarrow{\text{transfer 100}} C)$$

$$\text{spawn}(C \xrightarrow{\text{transfer 100}} D\ ) \qquad \text{spawn}(D \xrightarrow{\text{transfer 100}} A)$$

Goal

- Isolation → exclusive access (Mutex Transaction)
- Parallelism
- Deadlock Freedom
- Causal Ordering

$$\text{spawn}(\&\text{mut A} \xrightarrow{\text{transfer 100}} \&\text{mut B})$$

$$\text{spawn}(\&\text{mut B} \xrightarrow{\text{transfer 100}} \&\text{mut C})$$

$$\text{spawn}(\&\text{mut C} \xrightarrow{\text{transfer 100}} \&\text{mut D})$$

$$\text{spawn}(\&\text{mut D} \xrightarrow{\text{transfer 100}} \&\text{mut A})$$

Goal

- Isolation $\rightarrow$ exclusive access (Mutex Transaction)
- Parallelism
- Deadlock Freedom
- Causal Ordering

$$\text{spawn}(\ \&\text{mut A} \xrightarrow{\text{transfer 100}} \&\text{mut B}) \qquad \text{spawn}(\ \&\text{mut B} \xrightarrow{\text{transfer 100}} \&\text{mut C})$$

Goal

- Isolation $\rightarrow$ exclusive access (Mutex Transaction)
- Parallelism
- Deadlock Freedom
- Causal Ordering

$$\text{spawn}(\ \&\text{mut A} \xrightarrow{\text{transfer 100}} \&\text{mut B})$$

$$\text{spawn}(\ \&\text{mut C} \xrightarrow{\text{transfer 100}} \&\text{mut D})$$

Goal

- Isolation → exclusive access (Mutex Transaction)
- Parallelism
- Deadlock Freedom → Deadlock avoidance (Sort)
- Causal Ordering

$$\text{spawn}(\&\text{mut A} \xrightarrow{\text{transfer 100}} \&\text{mut B}) \qquad \text{spawn}(\&\text{mut B} \xrightarrow{\text{transfer 100}} \&\text{mut C})$$

$$\text{spawn}(\&\text{mut C} \xrightarrow{\text{transfer 100}} \&\text{mut D}) \qquad \text{spawn}(\&\text{mut D} \xrightarrow{\text{transfer 100}} \&\text{mut A})$$

Goal

- Isolation → exclusive access (Mutex Transaction)
- Parallelism
- Deadlock Freedom → Deadlock avoidance (Sort)
- Ordering → DAG (Dependency Graph)

$$\text{spawn}(\&\text{mut A} \xrightarrow{\text{transfer 100}} \&\text{mut B})$$

$$\text{spawn}(\&\text{mut B} \xrightarrow{\text{transfer 100}} \&\text{mut C})$$

$$\text{spawn}(\&\text{mut C} \xrightarrow{\text{transfer 100}} \&\text{mut D})$$

$$\text{spawn}(\&\text{mut D} \xrightarrow{\text{transfer 100}} \&\text{mut A})$$

Goal

- Isolation → exclusive access (Mutex Transaction)
- Parallelism
- Deadlock Freedom → Deadlock avoidance (Sort)
- Causal Ordering → DAG (Dependency Graph)

$$\text{spawn}(\&\text{mut A} \xrightarrow{\text{transfer 100}} \&\text{mut B}) \qquad \text{spawn}(\&\text{mut B} \xrightarrow{\text{transfer 100}} \&\text{mut C})$$

$$\text{spawn}(\&\text{mut C} \xrightarrow{\text{transfer 100}} \&\text{mut D}) \qquad \text{spawn}(\&\text{mut D} \xrightarrow{\text{transfer 100}} \&\text{mut A})$$

BoC in nutshell

- Cown: protects a piece of separated data → Mutex
- Behaviour: unit of concurrent execution → Thread
- When: spawns a behaviour with a set of required cowns → Spawn

$$\text{when(Cown<A>, Cown<B>; \&mut A} \xrightarrow{\text{transfer 100}} \text{\&mut B)}$$

$$\text{when(Cown<B>, Cown<C>; \&mut B} \xrightarrow{\text{transfer 100}} \text{\&mut C)}$$

$$\text{when(Cown<C>, Cown<D>; \&mut C} \xrightarrow{\text{transfer 100}} \text{\&mut D)}$$

$$\text{when(Cown<D>, Cown<A>; \&mut D} \xrightarrow{\text{transfer 100}} \text{\&mut A)}$$

BoC in nutshell

- Cown: protects a piece of separated data → Mutex
- Behaviour: unit of concurrent execution → Thread
- When: spawns a behaviour with a set of required cowns → Spawn

$$\text{when(Cown<A>, Cown<B>; \&mut A} \xrightarrow{\text{transfer 100}} \text{\&mut B)}$$

$$\text{when(Cown<B>, Cown<C>; \&mut B} \xrightarrow{\text{transfer 100}} \text{\&mut C)}$$

$$\text{when(Cown<C>, Cown<D>; \&mut C} \xrightarrow{\text{transfer 100}} \text{\&mut D)}$$

$$\text{when(Cown<D>, Cown<A>; \&mut D} \xrightarrow{\text{transfer 100}} \text{\&mut A)}$$

BoC in nutshell

- Cown: protects a piece of separated data → Mutex
- Behaviour: unit of concurrent execution → Thread
- When: spawns a behaviour with a set of required cowns → Spawn

$$\text{when(Cown<A>, Cown<B>; \&mut A} \xrightarrow{\text{transfer 100}} \text{\&mut B)}$$

$$\text{when(Cown<B>, Cown<C>; \&mut B} \xrightarrow{\text{transfer 100}} \text{\&mut C)}$$

$$\text{when(Cown<C>, Cown<D>; \&mut C} \xrightarrow{\text{transfer 100}} \text{\&mut D)}$$

$$\text{when(Cown<D>, Cown<A>; \&mut D} \xrightarrow{\text{transfer 100}} \text{\&mut A)}$$

BoC in nutshell

- Cown: protects a piece of separated data → Mutex
- Behaviour: unit of concurrent execution → Thread
- When: spawns a behaviour with a set of required cowns → Spawn

$$\text{when(Cown<A>, Cown<B>; \&mut A} \xrightarrow{\text{transfer 100}} \text{\&mut B)}$$

$$\text{when(Cown<B>, Cown<C>; \&mut B} \xrightarrow{\text{transfer 100}} \text{\&mut C)}$$

$$\text{when(Cown<C>, Cown<D>; \&mut C} \xrightarrow{\text{transfer 100}} \text{\&mut D)}$$

$$\text{when(Cown<D>, Cown<A>; \&mut D} \xrightarrow{\text{transfer 100}} \text{\&mut A)}$$

BoC in nutshell

- Cown: protects a piece of separated data → Mutex
- Behaviour: unit of concurrent execution → Thread
- When: spawns a behaviour with a set of required cowns → Spawn

$$\text{when(Cown<A>, Cown<B>; \&mut A} \xrightarrow{\text{transfer 100}} \text{\&mut B)}$$

$$\text{when(Cown<B>, Cown<C>; \&mut B} \xrightarrow{\text{transfer 100}} \text{\&mut C)}$$

$$\text{when(Cown<C>, Cown<D>; \&mut C} \xrightarrow{\text{transfer 100}} \text{\&mut D)}$$

$$\text{when(Cown<D>, Cown<A>; \&mut D} \xrightarrow{\text{transfer 100}} \text{\&mut A)}$$

Abstraction

Example:

```
when (c1)      { /* b1 */ }
when (c3)      { /* b2 */ }
when (c1, c2) { /* b3 */ }
when (c1)      { /* b4 */ }
when (c2, c3) { /* b5 */ }
when (c3)      { /* b6 */ }
```

```
when (c1)      { /* b1 */ }
when (c3)      { /* b2 */ }
when (c1, c2)  { /* b3 */ }
when (c1)      { /* b4 */ }
when (c2, c3)  { /* b5 */ }
when (c3)      { /* b6 */ }
```

c3

c2

c1

```
when (c1)
{ /* b1 */ }
```

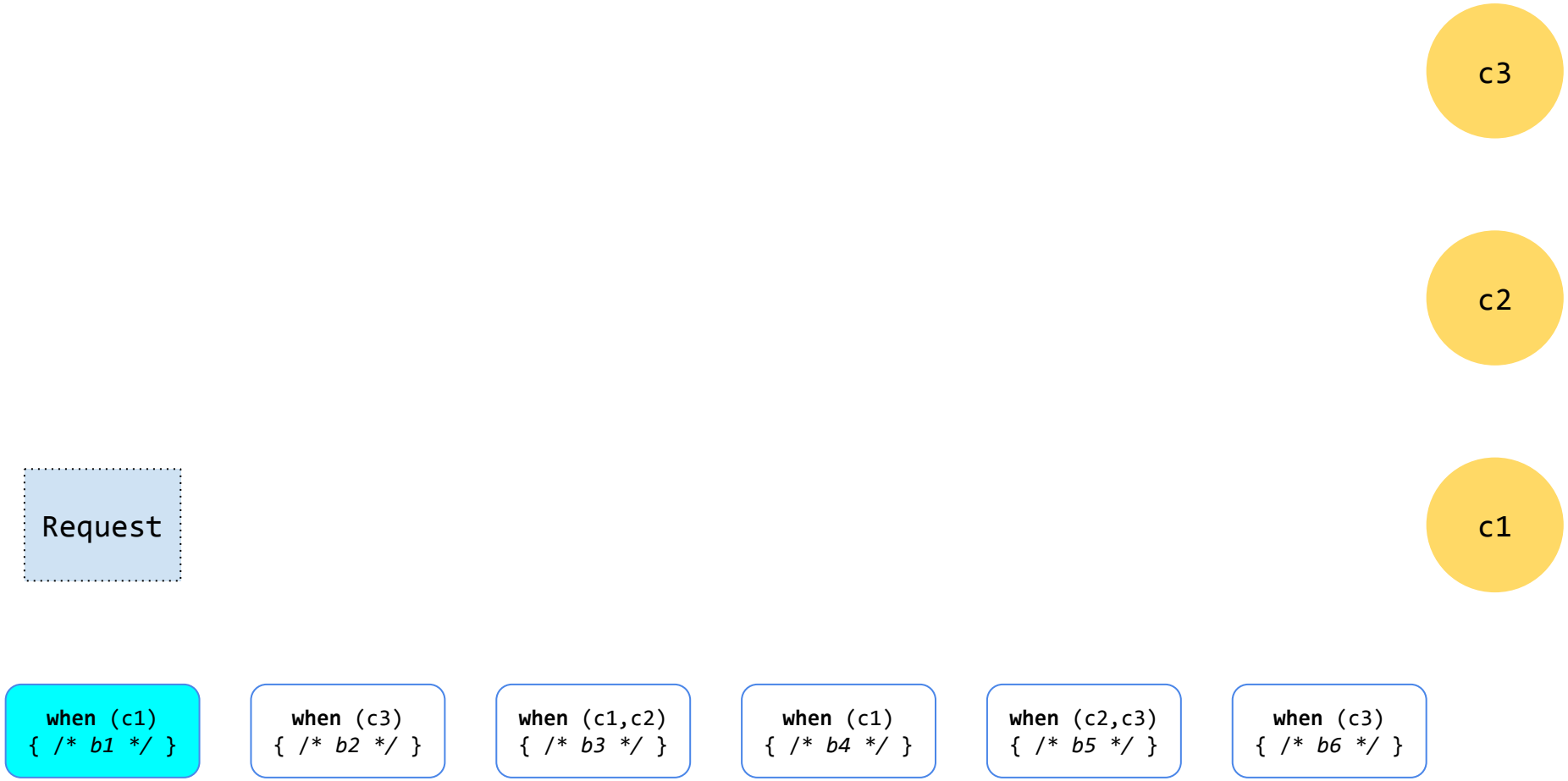
```
when (c3)
{ /* b2 */ }
```

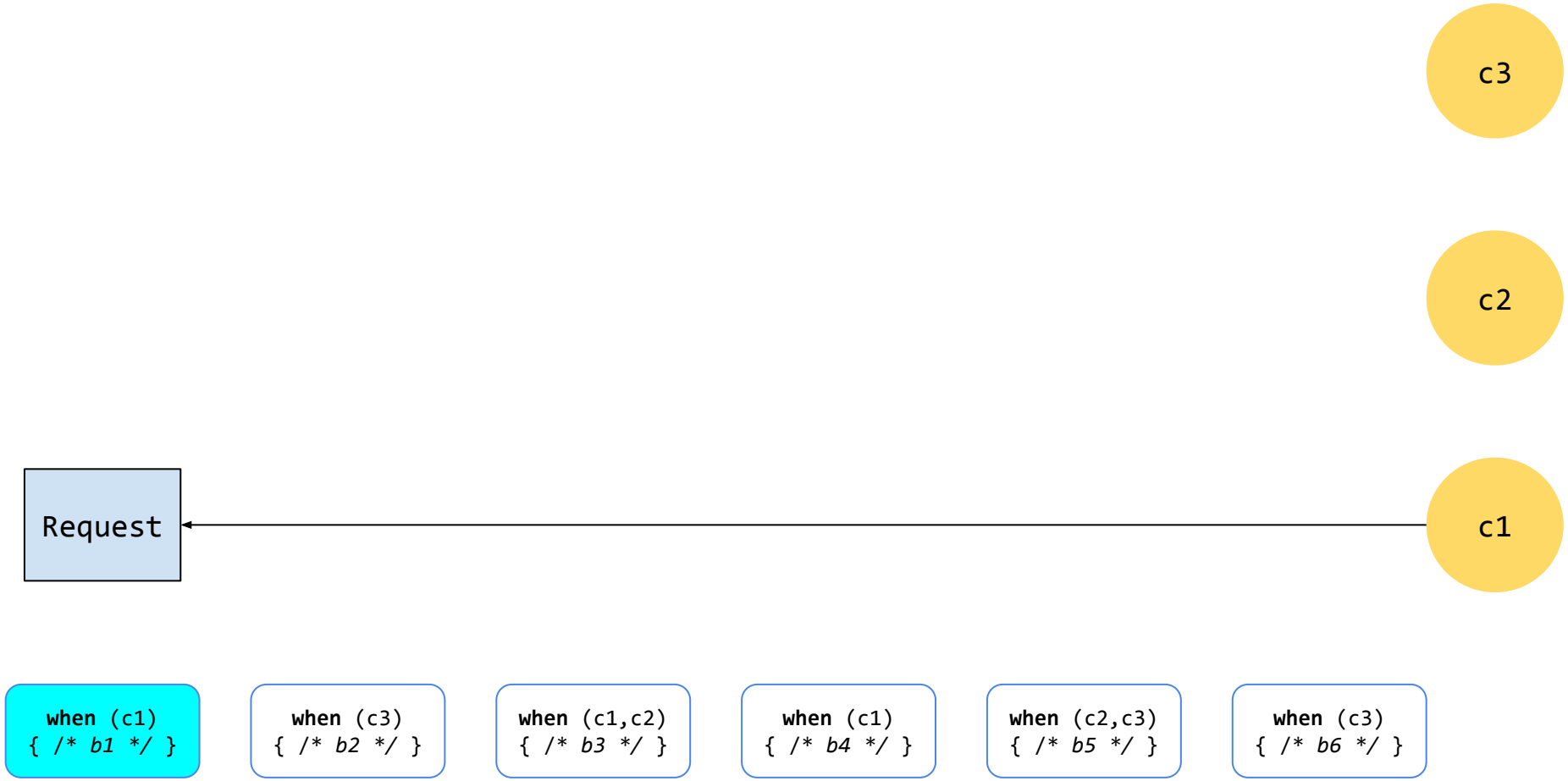
```
when (c1,c2)
{ /* b3 */ }
```

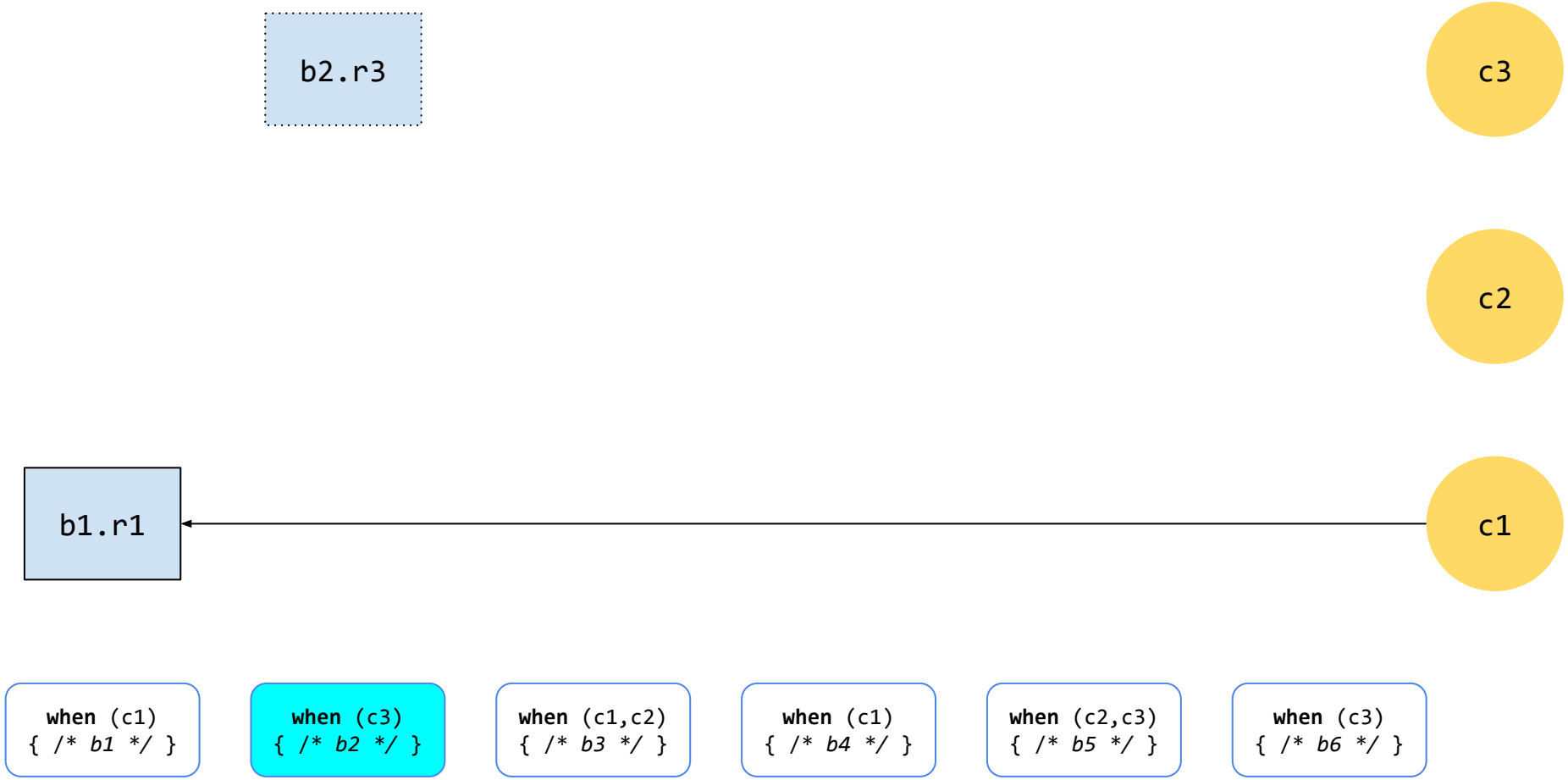
```
when (c1)
{ /* b4 */ }
```

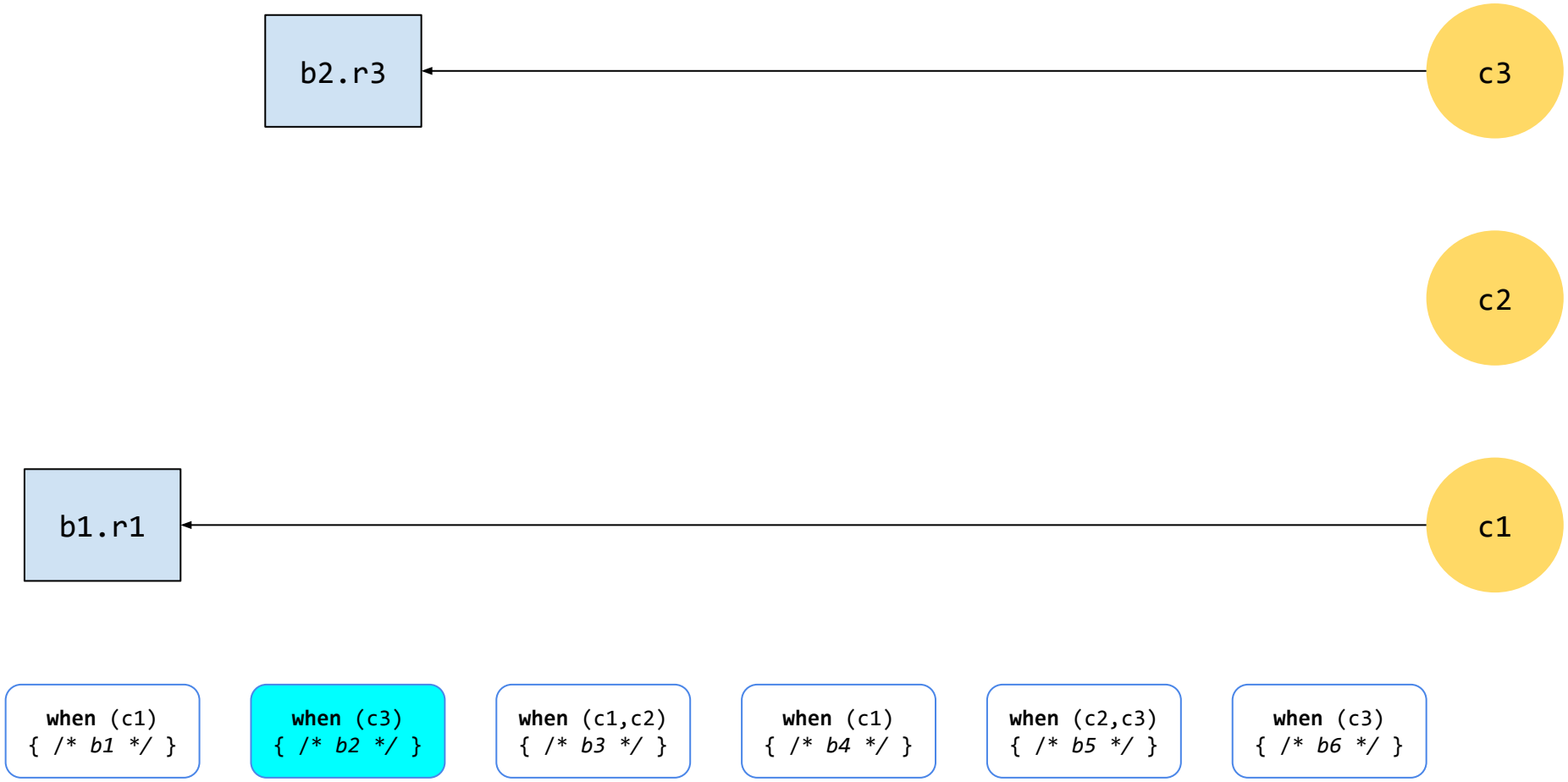
```
when (c2,c3)
{ /* b5 */ }
```

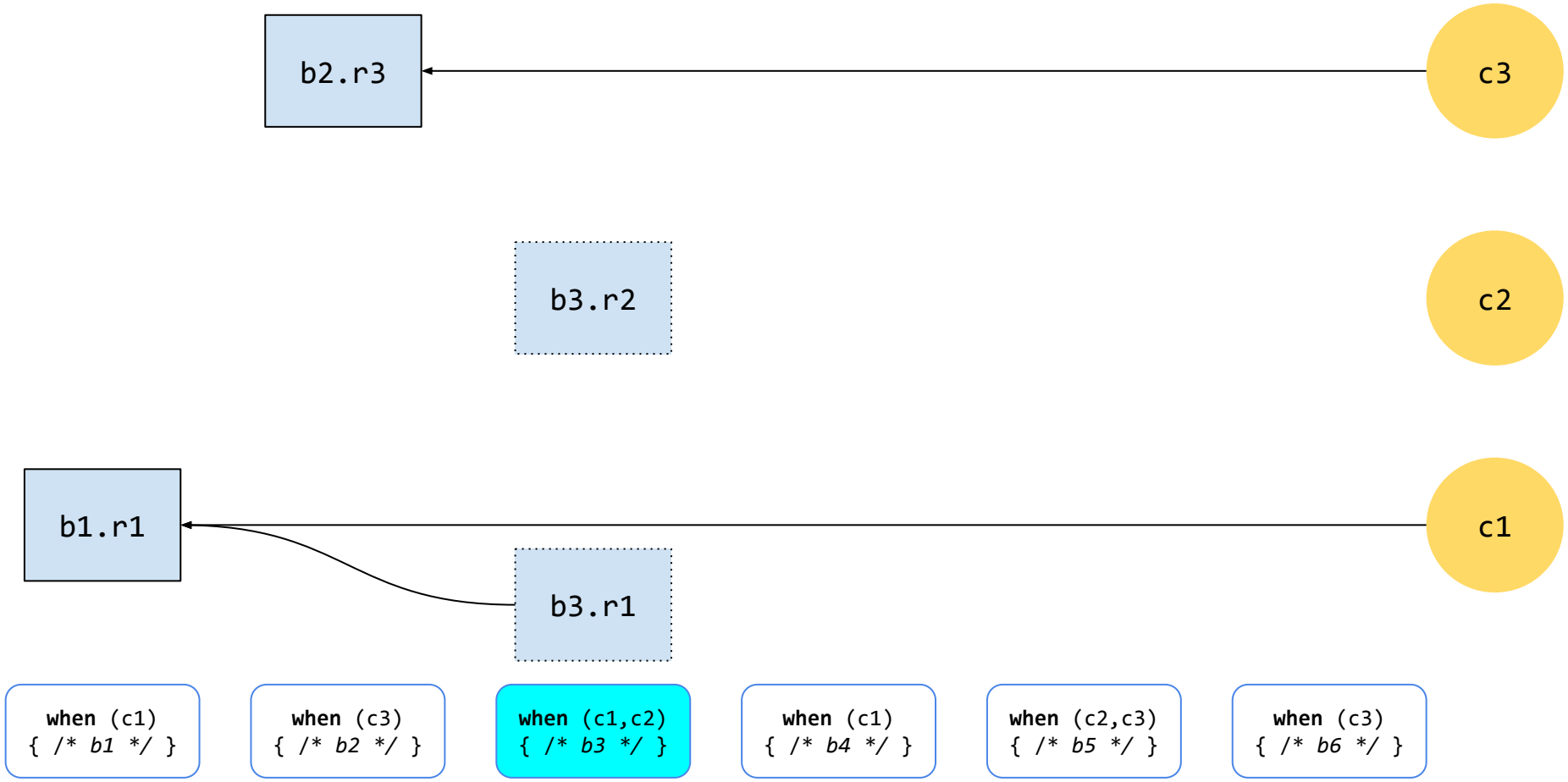
```
when (c3)
{ /* b6 */ }
```

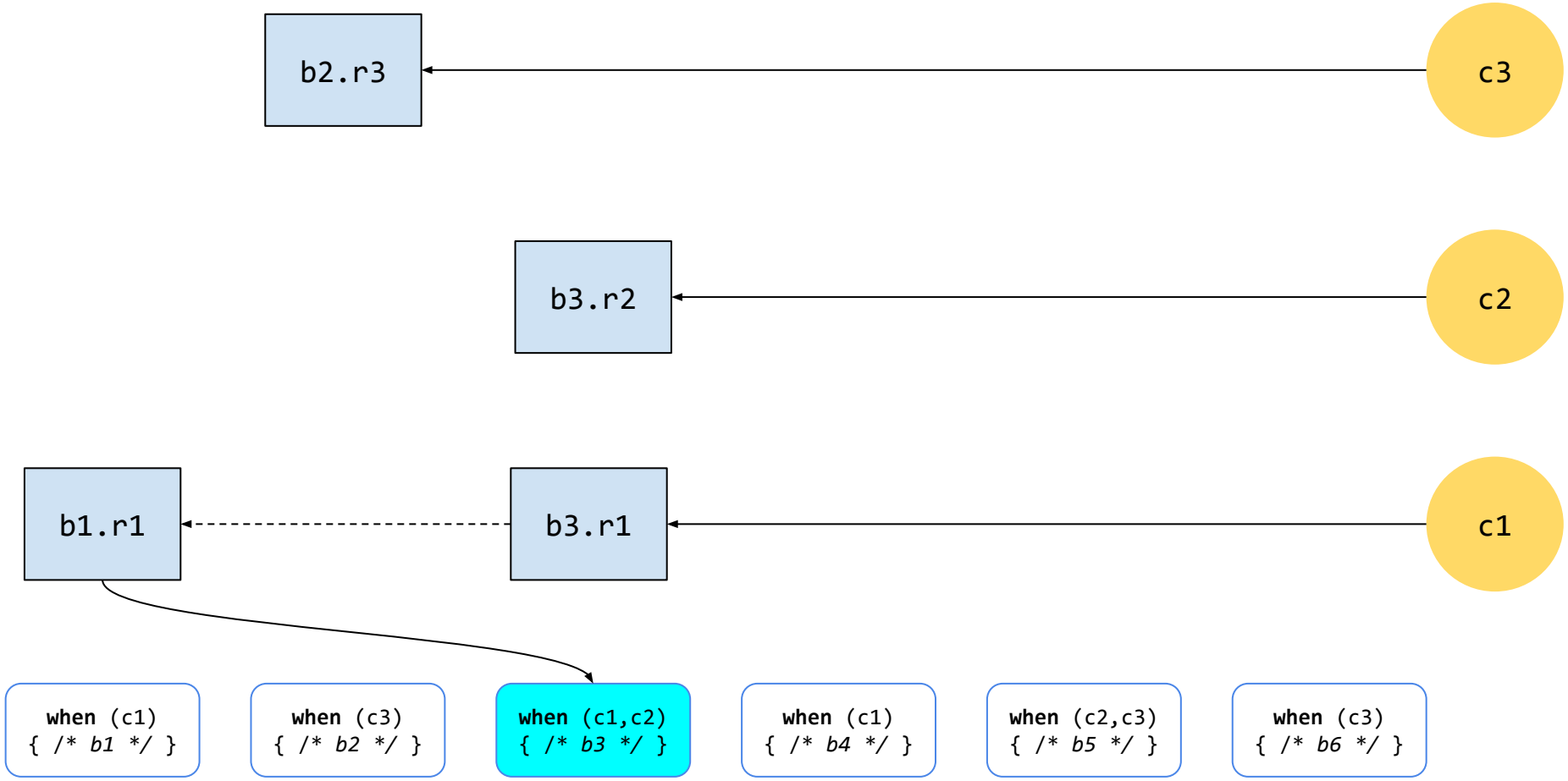

c3
c2
c1
Request
when (c1)
{ /* b1 */ }
when (c3)
{ /* b2 */ }
when (c1,c2)
{ /* b3 */ }
when (c1)
{ /* b4 */ }
when (c2,c3)
{ /* b5 */ }
when (c3)
{ /* b6 */ }

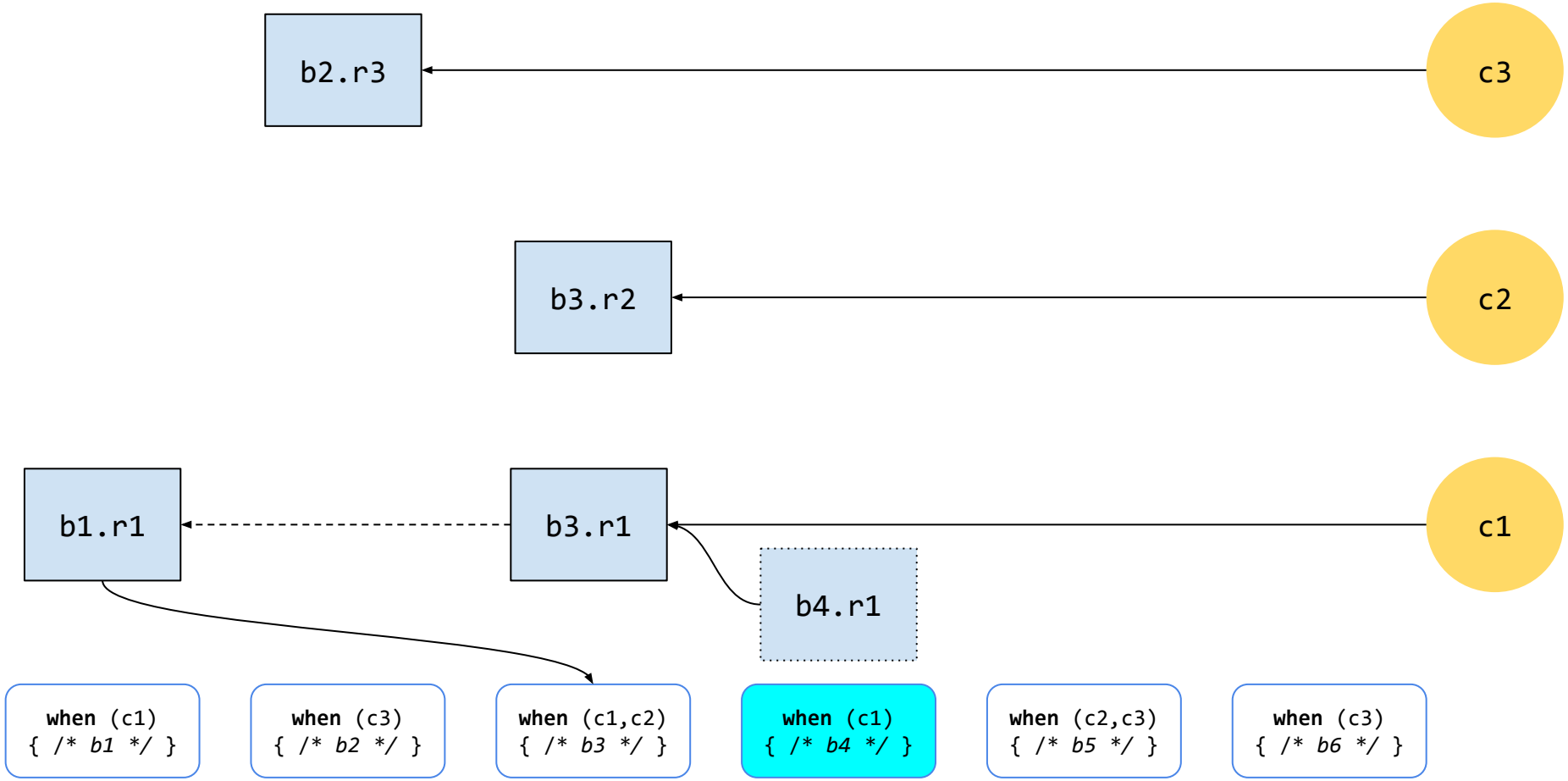

c3
c2
c1
Request
when (c1)
{ /* b1 */ }
when (c3)
{ /* b2 */ }
when (c1,c2)
{ /* b3 */ }
when (c1)
{ /* b4 */ }
when (c2,c3)
{ /* b5 */ }
when (c3)
{ /* b6 */ }

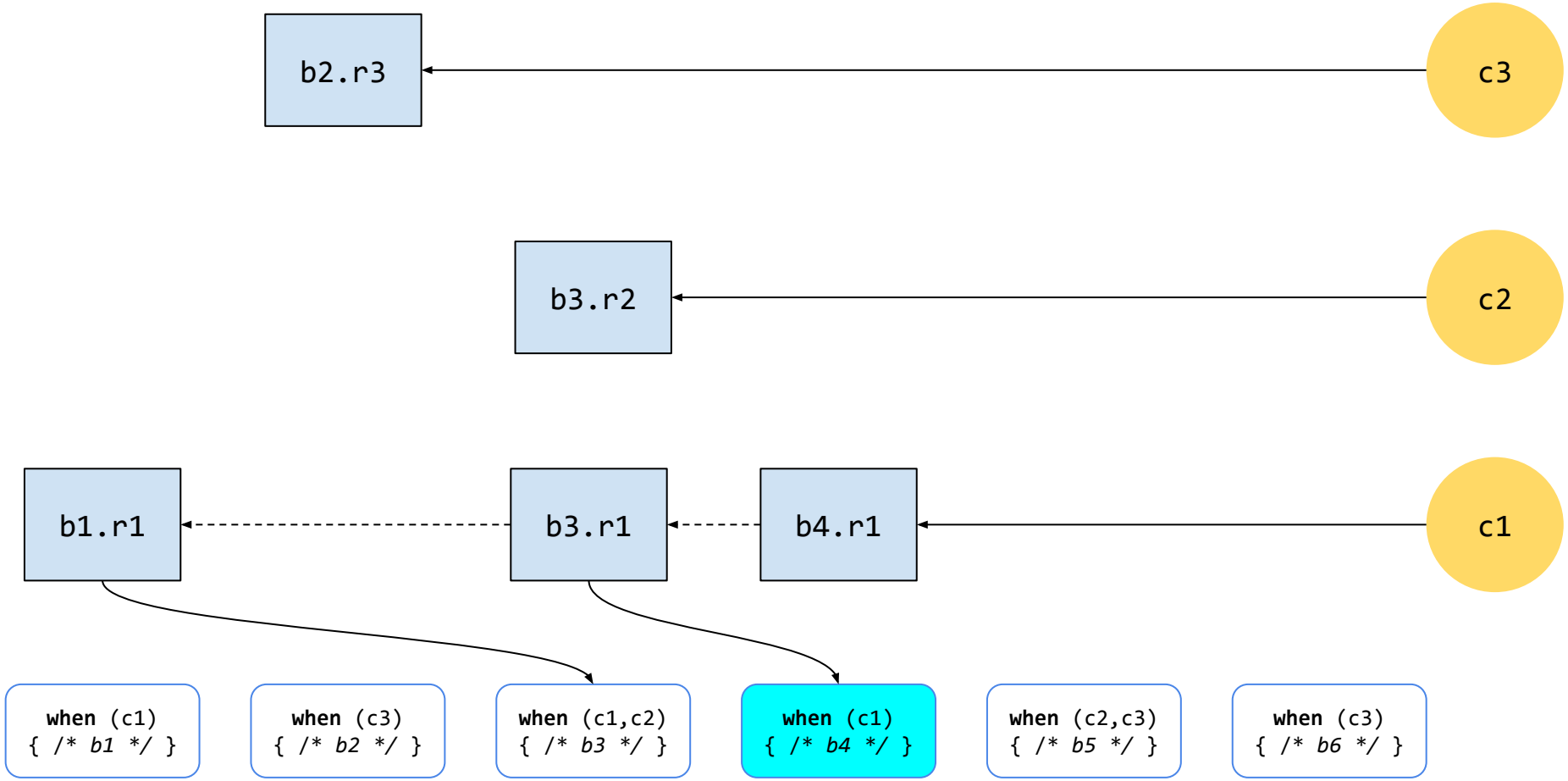

b2.r3
c3
c2
b1.r1
c1
when (c1)
{ /* b1 */ }
when (c3)
{ /* b2 */ }
when (c1,c2)
{ /* b3 */ }
when (c1)
{ /* b4 */ }
when (c2,c3)
{ /* b5 */ }
when (c3)
{ /* b6 */ }

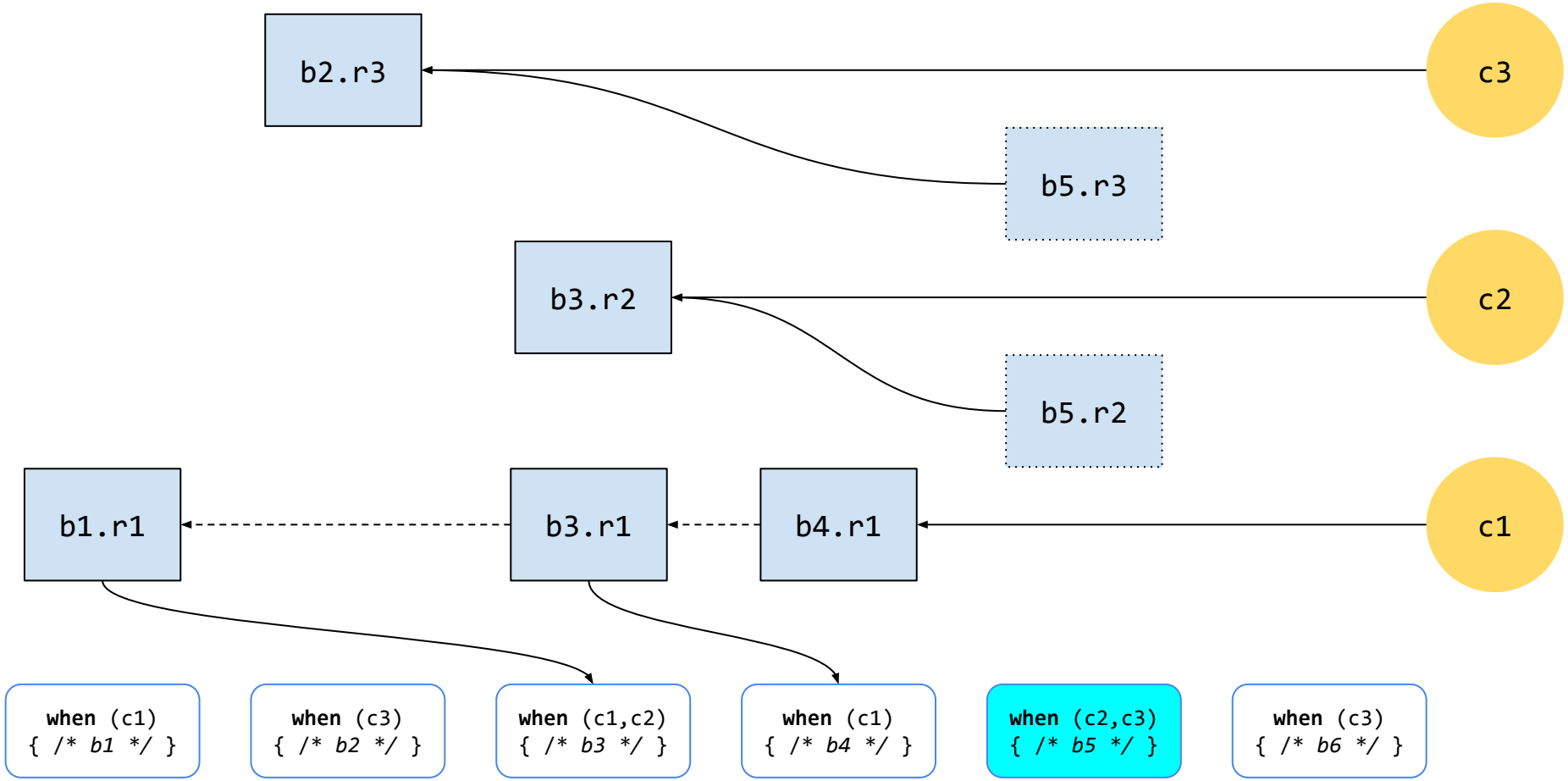

b2.r3
c3
c2
b1.r1
c1
when (c1)
{ /* b1 */ }
when (c3)
{ /* b2 */ }
when (c1,c2)
{ /* b3 */ }
when (c1)
{ /* b4 */ }
when (c2,c3)
{ /* b5 */ }
when (c3)
{ /* b6 */ }

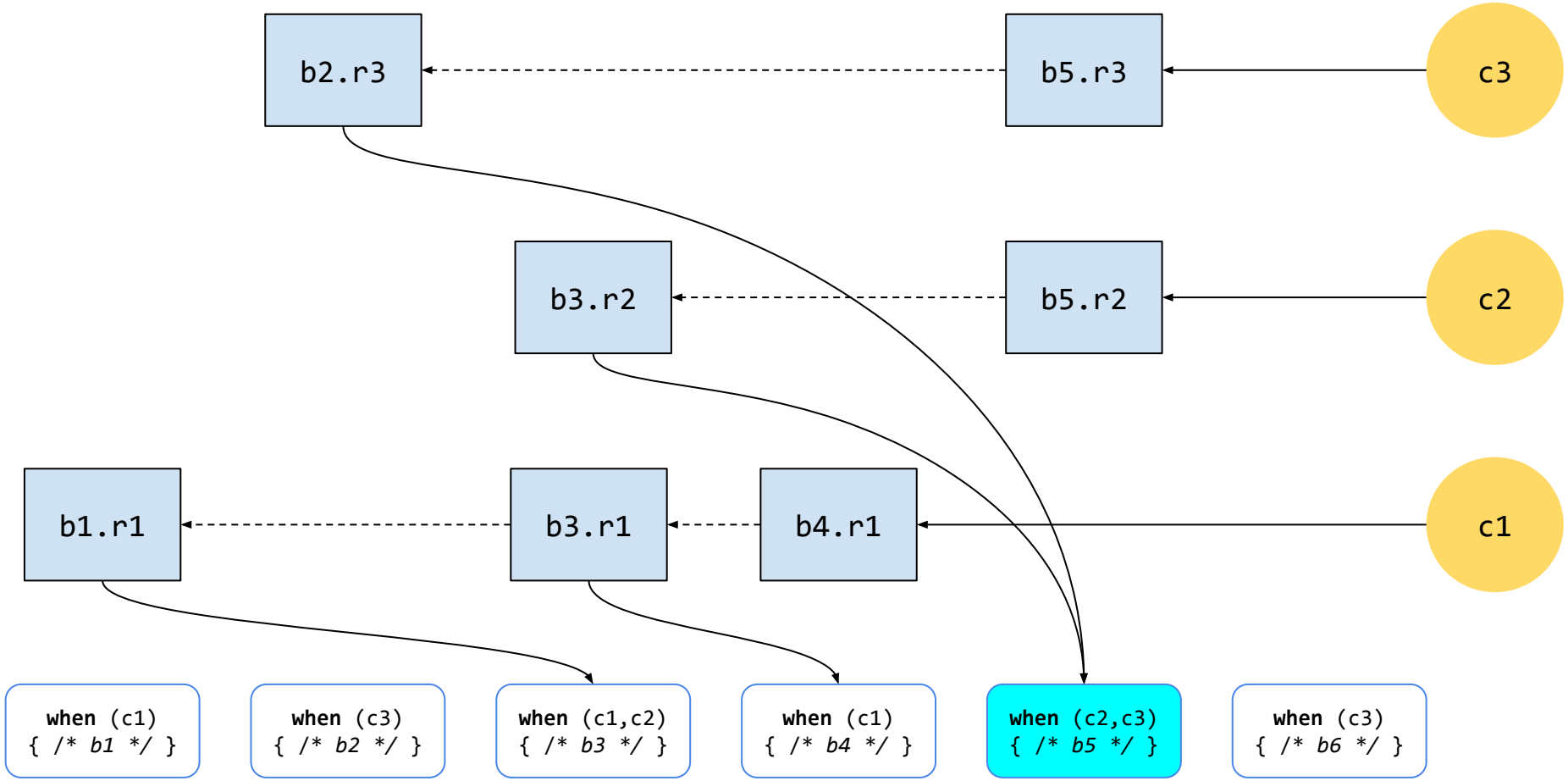

b2.r3
c3
b3.r2
c2
b1.r1
c1
b3.r1
when (c1)
{ /* b1 */ }
when (c3)
{ /* b2 */ }
when (c1,c2)
{ /* b3 */ }
when (c1)
{ /* b4 */ }
when (c2,c3)
{ /* b5 */ }
when (c3)
{ /* b6 */ }

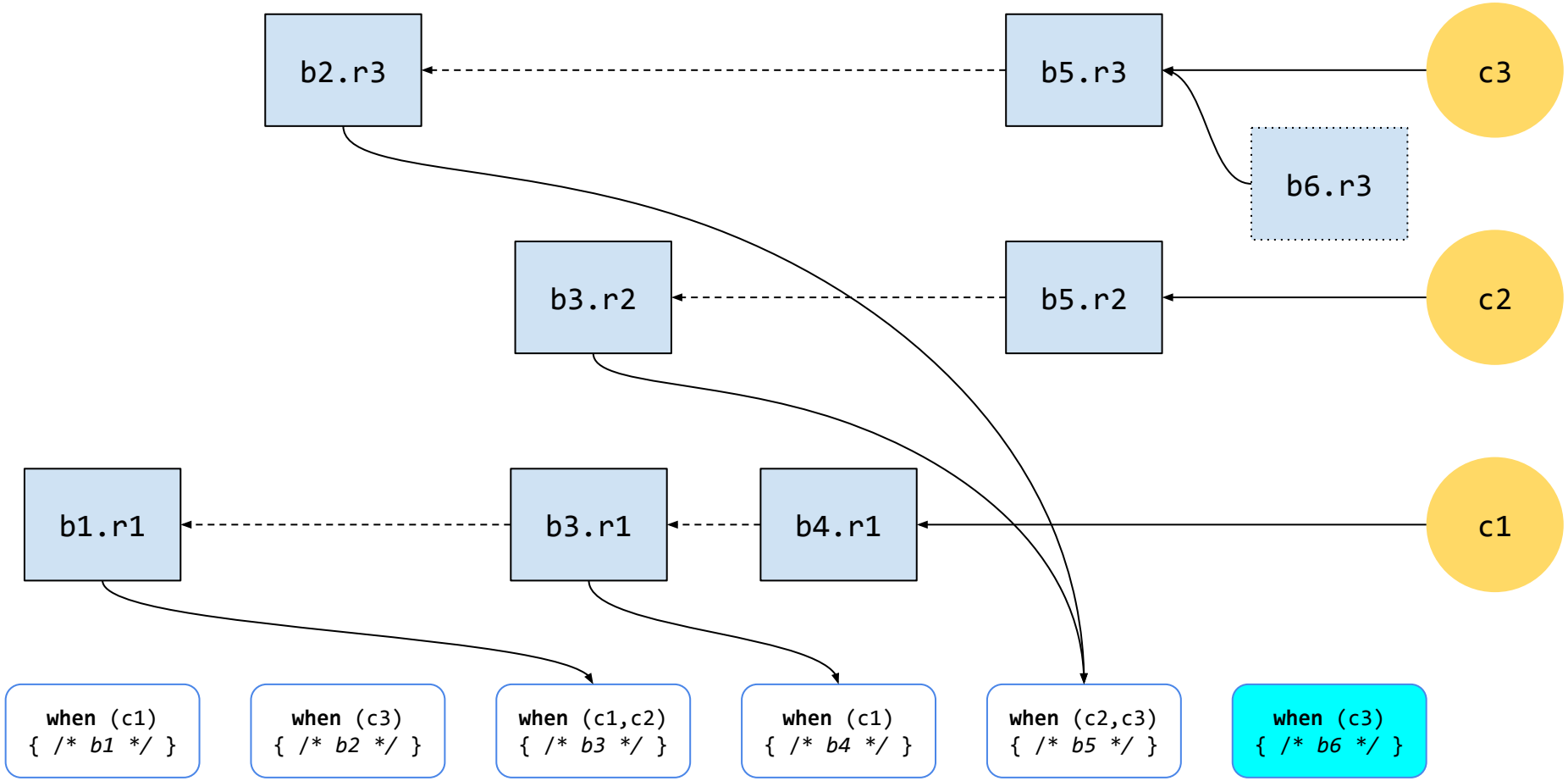

b2.r3
c3
b3.r2
c2
b1.r1
b3.r1
c1
when (c1)
{ /* b1 */ }
when (c3)
{ /* b2 */ }
when (c1,c2)
{ /* b3 */ }
when (c1)
{ /* b4 */ }
when (c2,c3)
{ /* b5 */ }
when (c3)
{ /* b6 */ }

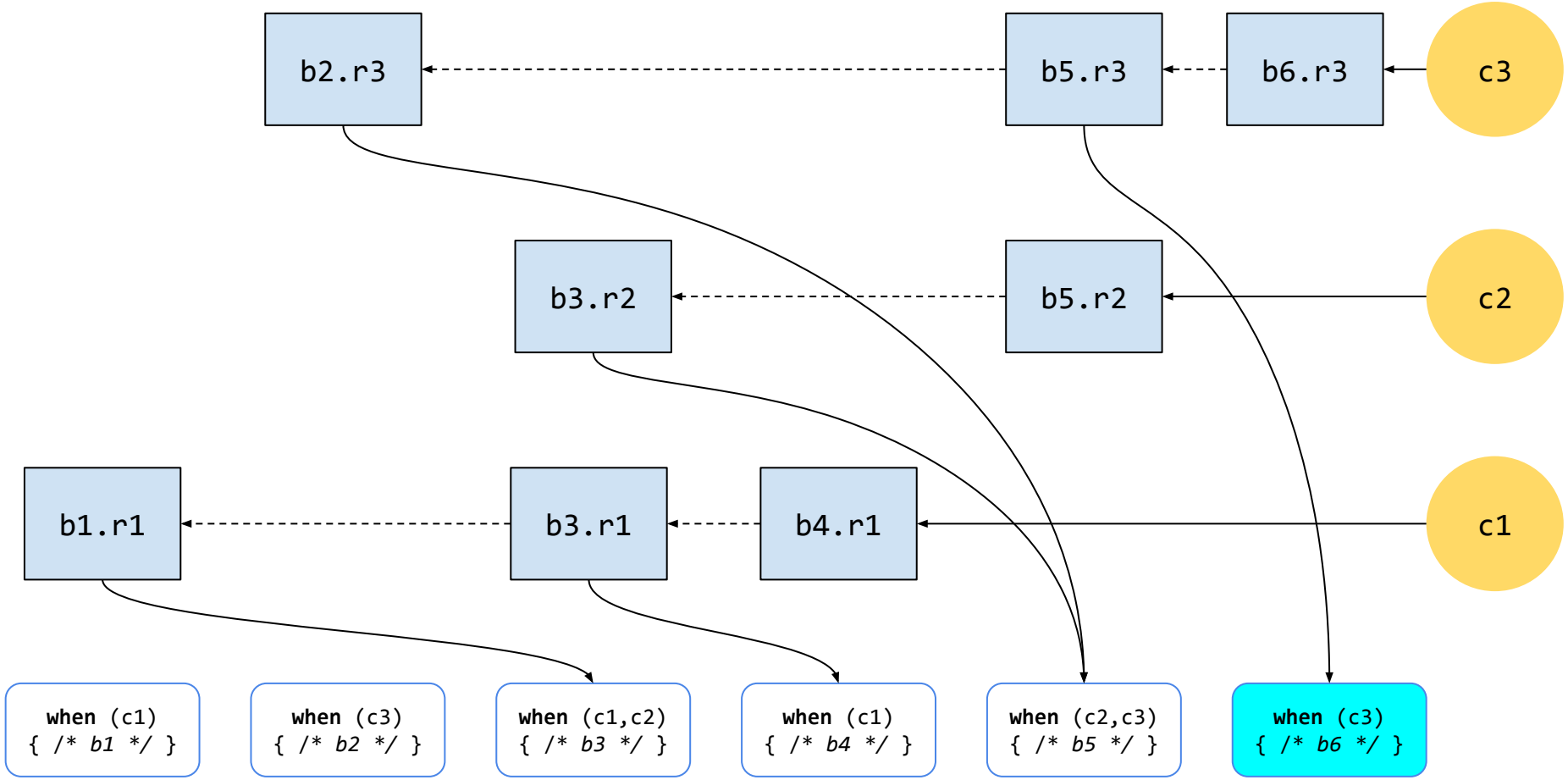

b2.r3
c3
b3.r2
c2
b1.r1
b3.r1
c1
b4.r1
when (c1)
{ /* b1 */ }
when (c3)
{ /* b2 */ }
when (c1,c2)
{ /* b3 */ }
when (c1)
{ /* b4 */ }
when (c2,c3)
{ /* b5 */ }
when (c3)
{ /* b6 */ }

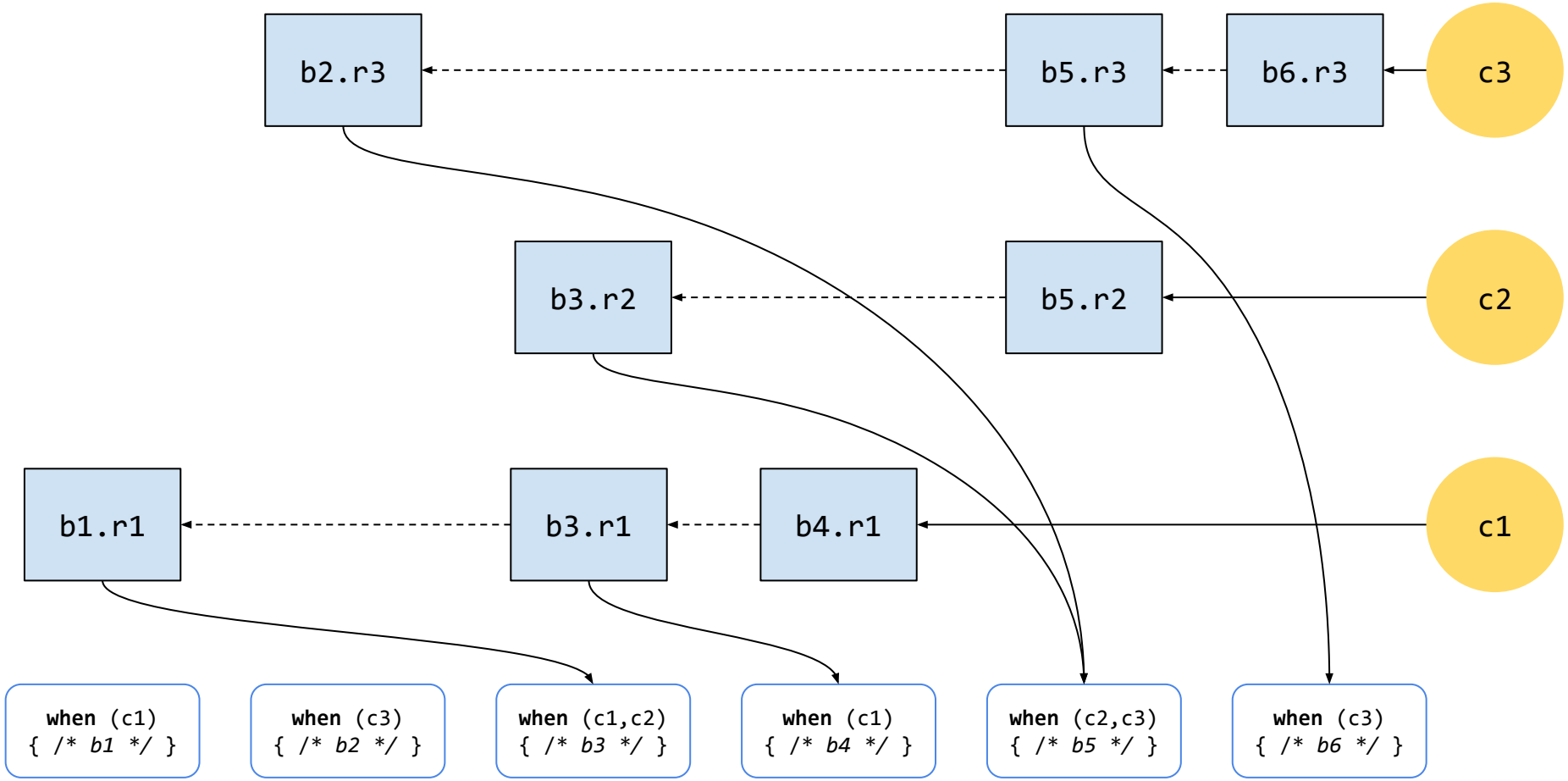

b2.r3
c3
b3.r2
c2
b1.r1
b3.r1
b4.r1
c1
when (c1)
{ /* b1 */ }
when (c3)
{ /* b2 */ }
when (c1,c2)
{ /* b3 */ }
when (c1)
{ /* b4 */ }
when (c2,c3)
{ /* b5 */ }
when (c3)
{ /* b6 */ }


b2.r3
c3
b5.r3
b3.r2
c2
b5.r2
b1.r1
b3.r1
b4.r1
c1
when (c1)
{ /* b1 */ }
when (c3)
{ /* b2 */ }
when (c1,c2)
{ /* b3 */ }
when (c1)
{ /* b4 */ }
when (c2,c3)
{ /* b5 */ }
when (c3)
{ /* b6 */ }


b2.r3
b5.r3
c3
b3.r2
b5.r2
c2
b1.r1
b3.r1
b4.r1
c1
when (c1)
{ /* b1 */ }
when (c3)
{ /* b2 */ }
when (c1,c2)
{ /* b3 */ }
when (c1)
{ /* b4 */ }
when (c2,c3)
{ /* b5 */ }
when (c3)
{ /* b6 */ }

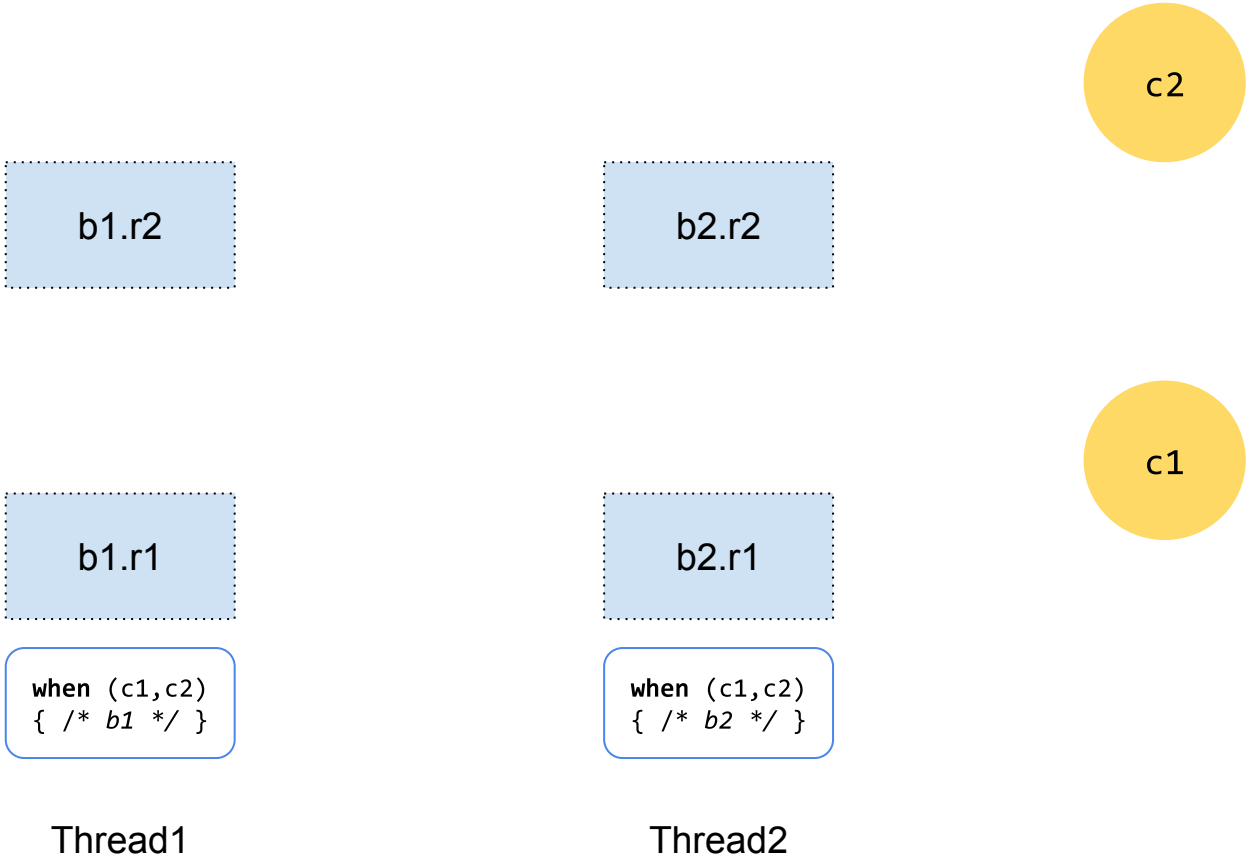

b2.r3
b5.r3
c3
b6.r3
b3.r2
b5.r2
c2
b1.r1
b3.r1
b4.r1
c1
when (c1)
{ /* b1 */ }
when (c3)
{ /* b2 */ }
when (c1,c2)
{ /* b3 */ }
when (c1)
{ /* b4 */ }
when (c2,c3)
{ /* b5 */ }
when (c3)
{ /* b6 */ }

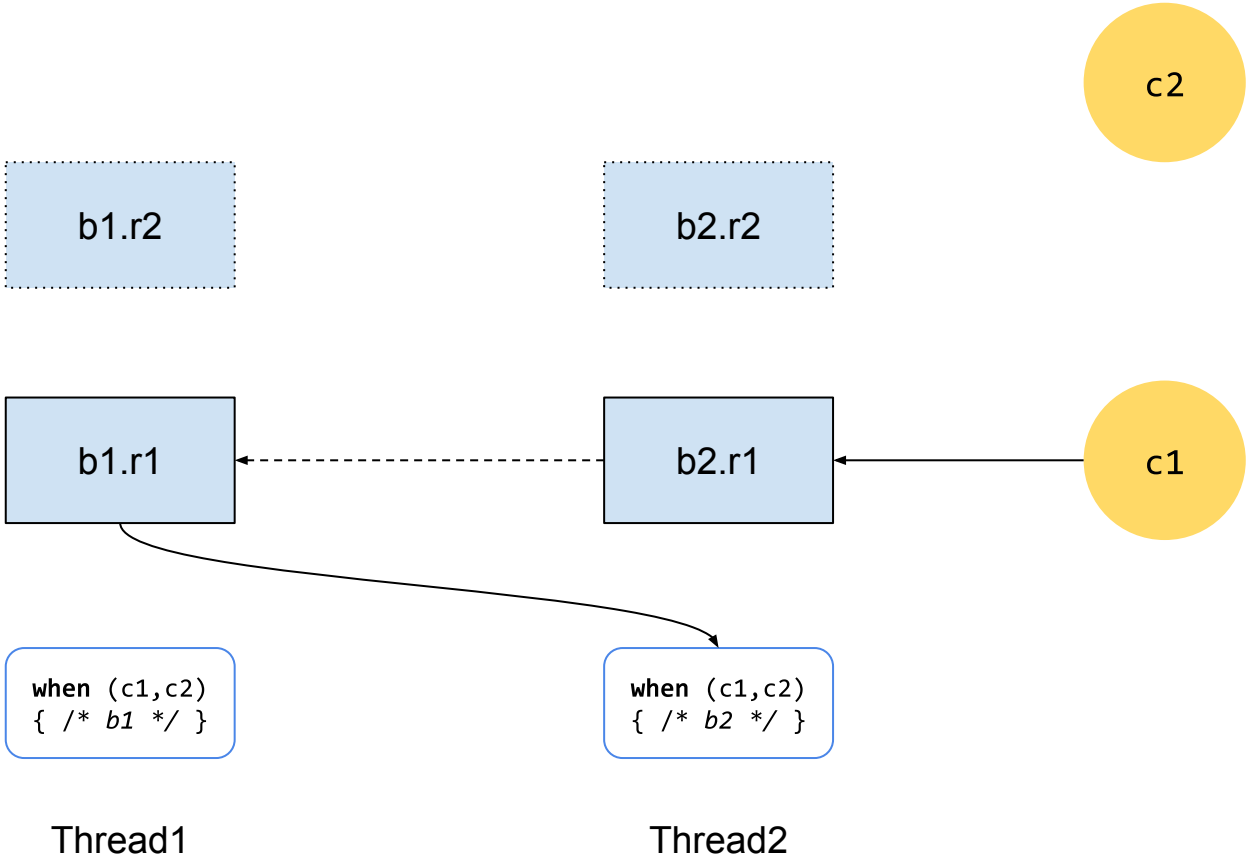

b2.r3
b5.r3
b6.r3
c3
b3.r2
b5.r2
c2
b1.r1
b3.r1
b4.r1
c1
when (c1)
{ /* b1 */ }
when (c3)
{ /* b2 */ }
when (c1,c2)
{ /* b3 */ }
when (c1)
{ /* b4 */ }
when (c2,c3)
{ /* b5 */ }
when (c3)
{ /* b6 */ }

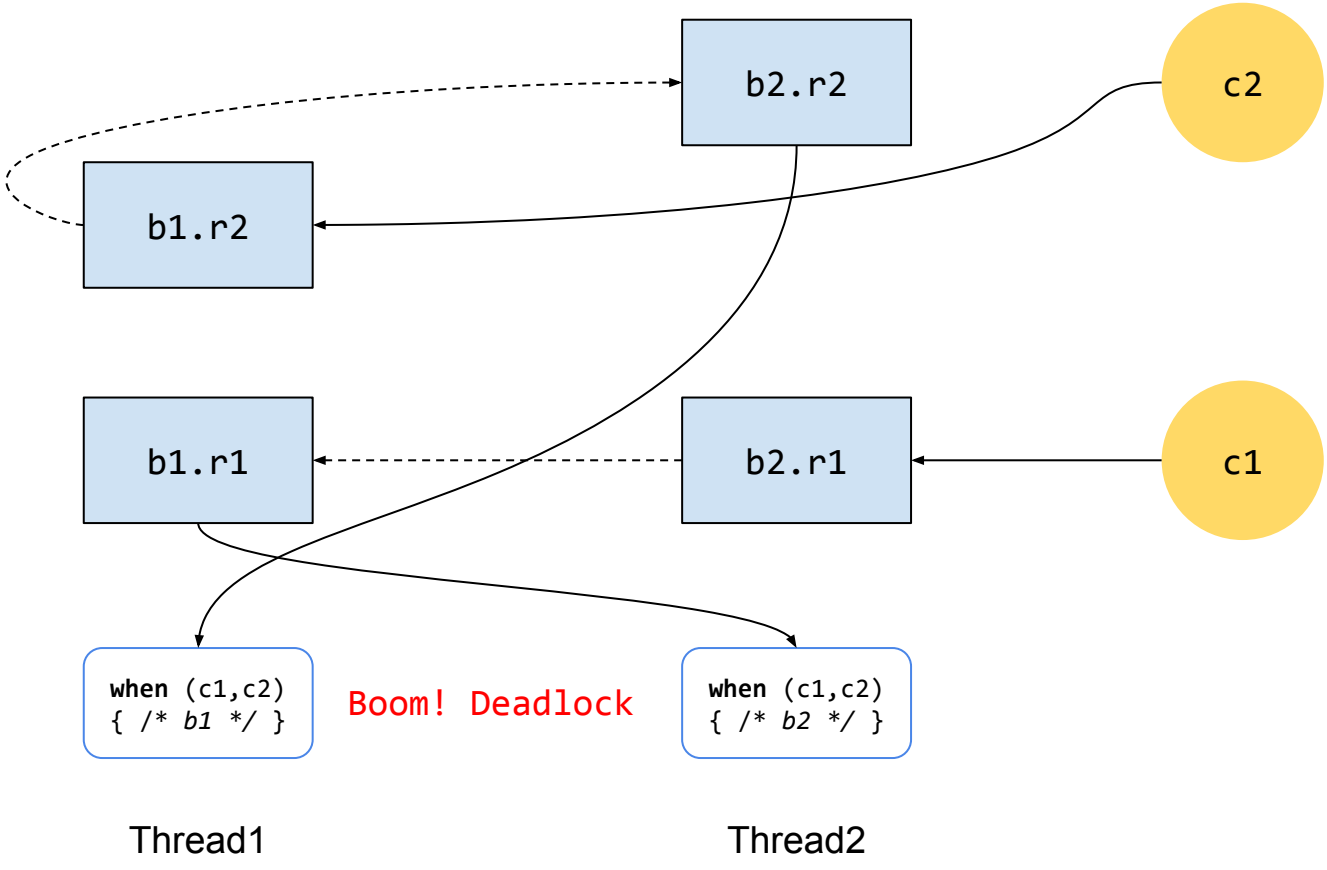

b2.r3
b5.r3
b6.r3
c3
b3.r2
b5.r2
c2
b1.r1
b3.r1
b4.r1
c1
when (c1) { /* b1 */ }
when (c3) { /* b2 */ }
when (c1,c2) { /* b3 */ }
when (c1) { /* b4 */ }
when (c2,c3) { /* b5 */ }
when (c3) { /* b6 */ }

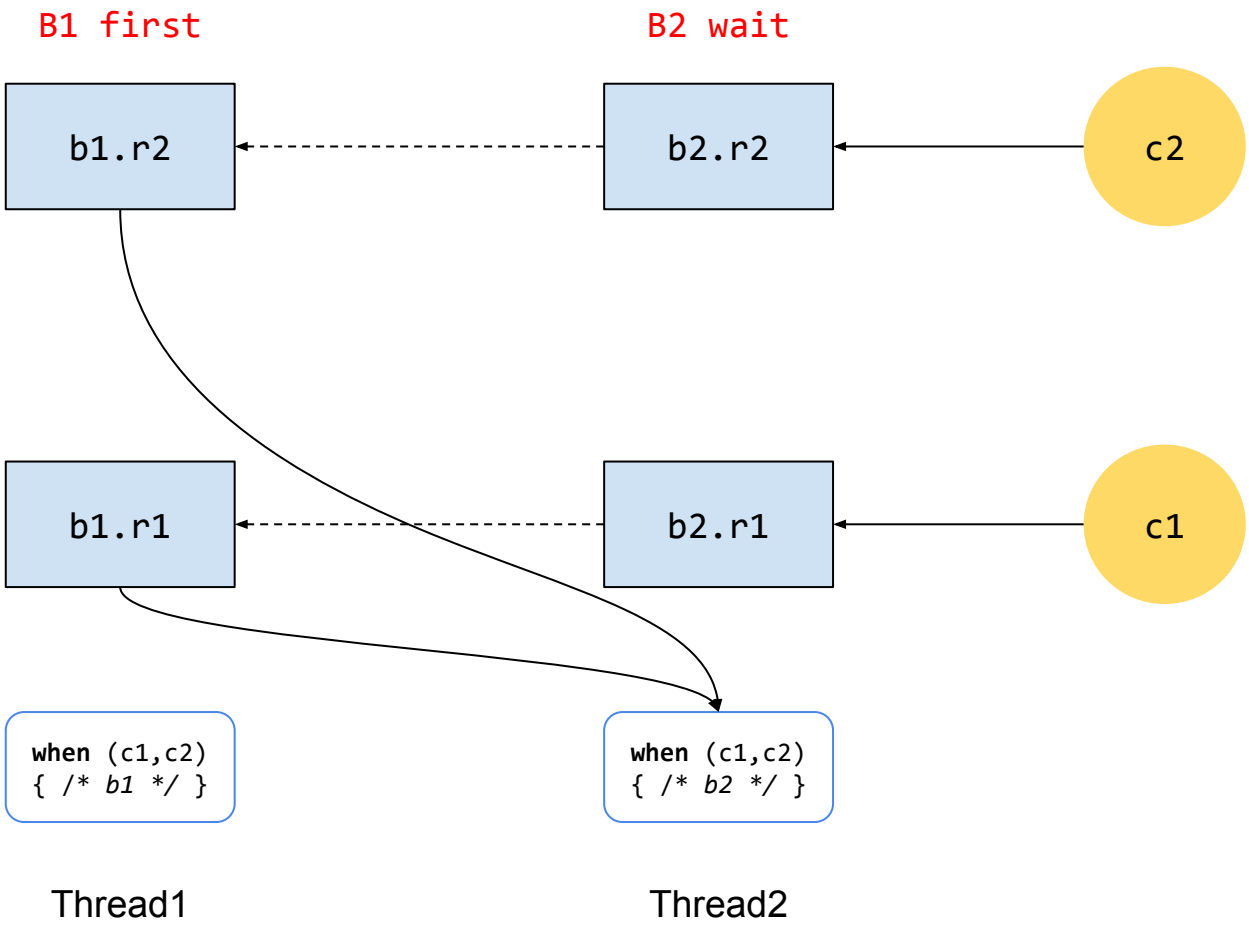
Implementation with lock

- Additional count
- Scheduled flag


c2
b1.r2
b2.r2
c1
b1.r1
b2.r1
when (c1,c2)
{ /* b1 */ }
when (c1,c2)
{ /* b2 */ }
Thread1
Thread2


c2
b1.r2
b2.r2
b1.r1
b2.r1
c1
when (c1,c2)
{ /* b1 */ }
when (c1,c2)
{ /* b2 */ }
Thread1
Thread2


b2.r2
c2
b1.r2
b1.r1
b2.r1
c1
when (c1,c2)
{ /* b1 */ }
Boom! Deadlock
when (c1,c2)
{ /* b2 */ }
Thread1
Thread2


B1 first
B2 wait
b1.r2
b2.r2
c2
b1.r1
b2.r1
c1
when (c1,c2)
{ /* b1 */ }
when (c1,c2)
{ /* b2 */ }
Thread1
Thread2

Implementation without lock

- Behaviour, Request, and Cown all on heap
- Pin semantics

Related topic

- Actor
- Transaction
- Distribute Programming

Thanks for watching!