An Overview of Céu

A synchronous language inspired by Esterel

Francisco Sant'Anna

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www.ceu-lang.org

“Hello world!” in Céu

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- Blinking a LED
    1. *on ↔ off every 500ms*

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```
loop do
    await 500ms;
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end
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par/or do
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with
    await PRESS;
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```

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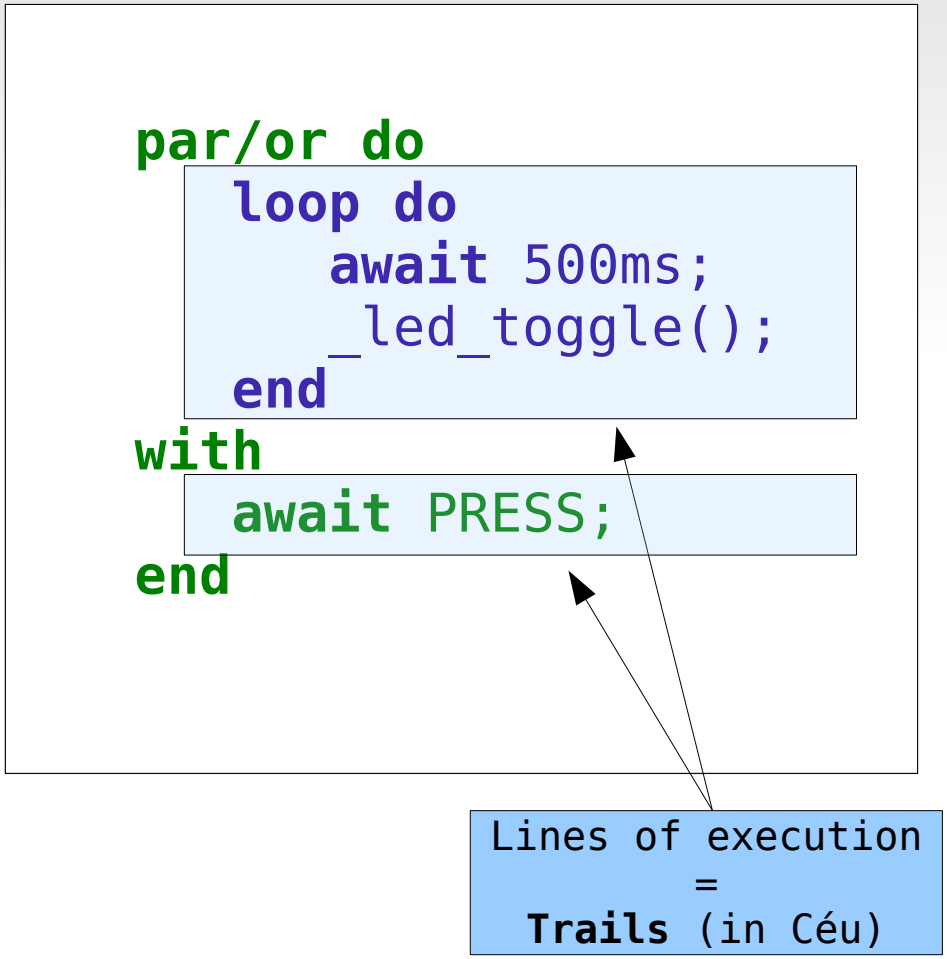
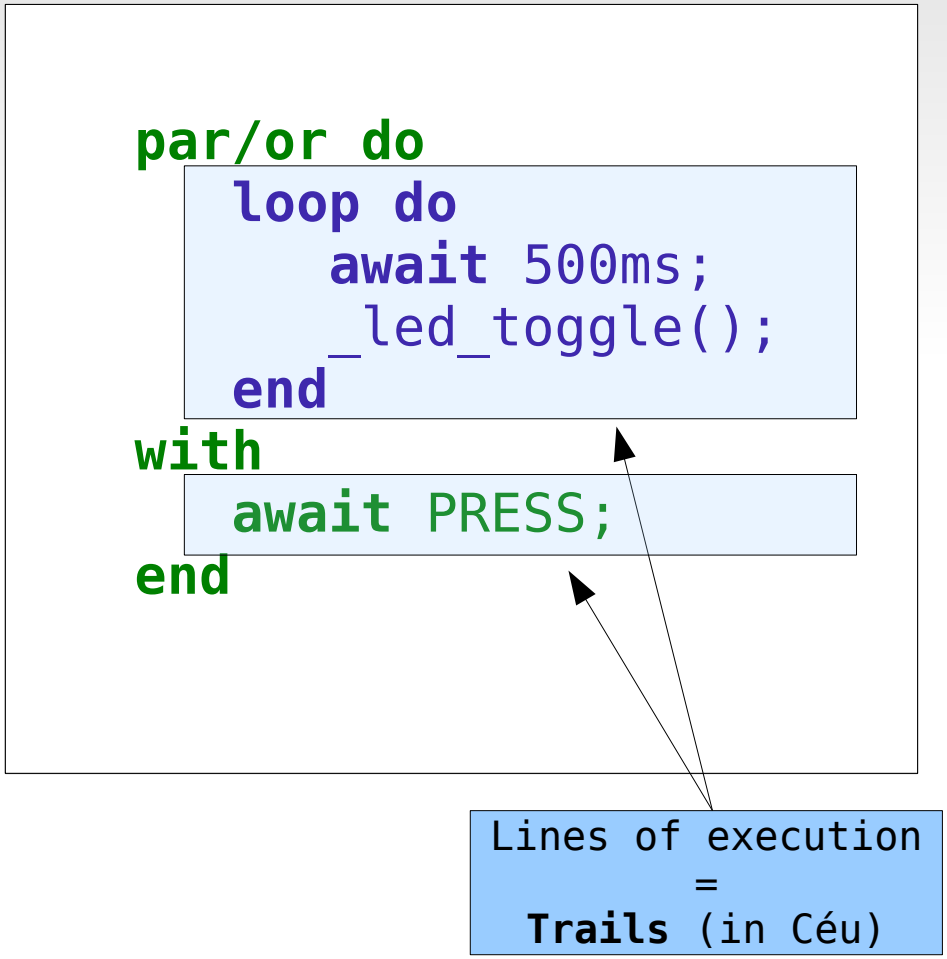


“Hello world!” in Céu

- Blinking a LED
  1. *on ↔ off every 500ms*
  2. *stop after “press”*
  3. *restart after 2s*



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        loop do
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        await PRESS;
    end
    await 2s;
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Lines of execution
=
Trails (in Céu)

“Hello world!” in Céu

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- Compositions
  - seq, loop, par *(trails)*
    - At any level of depth

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      loop do
         await 500ms;
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- Compositions
  - seq, loop, par *(trails)*
    - At any level of depth
  - ~~state variables / communication~~

```
loop do
   par/or do
      loop do
         await 500ms;
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      end
   with
      await PRESS;
   end
   await 2s;
end
```

Lines of execution = **Trails** (in Céu)

Céu is heavily inspired by Esterel

Céu Peculiarities

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1. External events

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    - notion of time ~ queue of unique events, mutual exclusion
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   - finalization for local/external resources
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15 min video at **`ceu-lang.org`**

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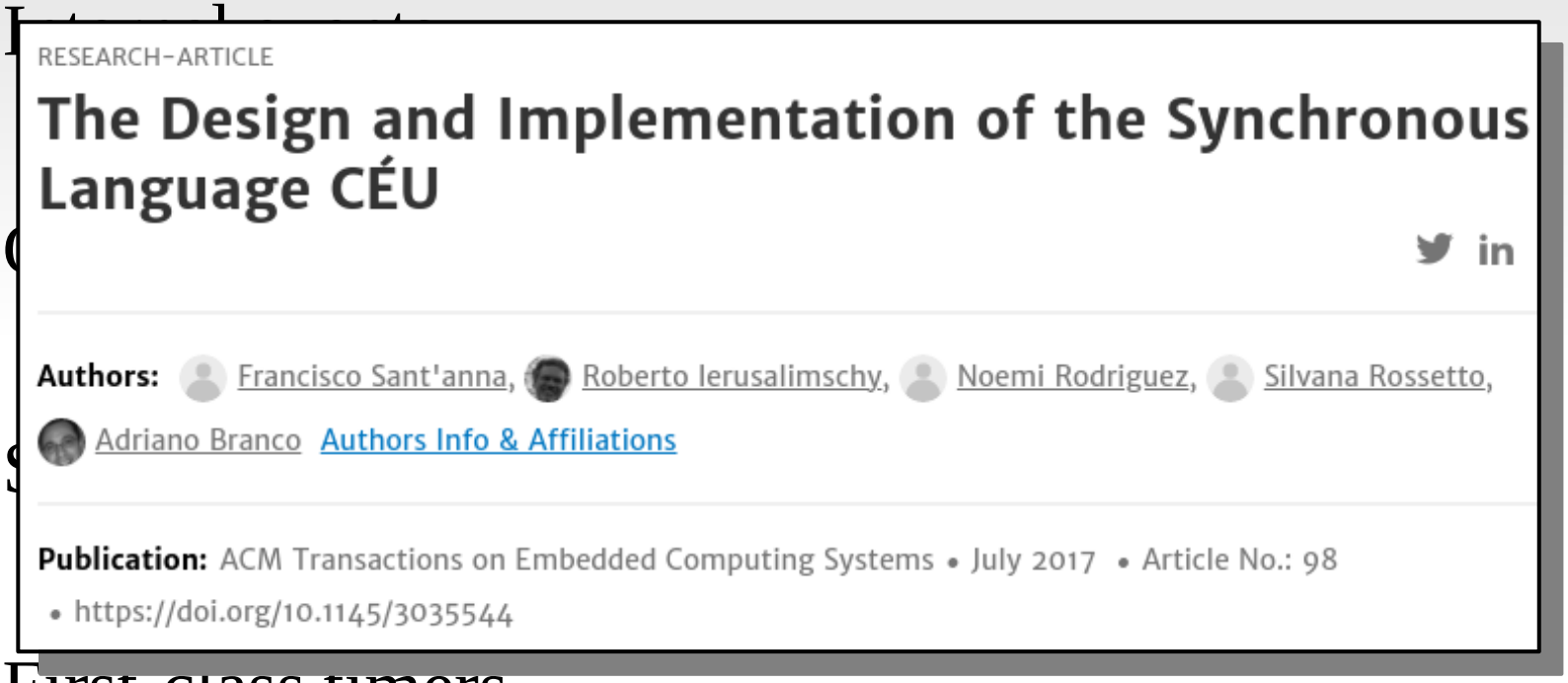

RESEARCH-ARTICLE

The Design and Implementation of the Synchronous Language CÉU

Authors: Francisco Sant'anna, Roberto Ierusalimschy, Noemi Rodriguez, Silvana Rossetto, Adriano Branco Authors Info & Affiliations

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15 min video at **`ceu-lang.org`**

1. External Events

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Esterel
(fixed tick)

Céu
(unique input)

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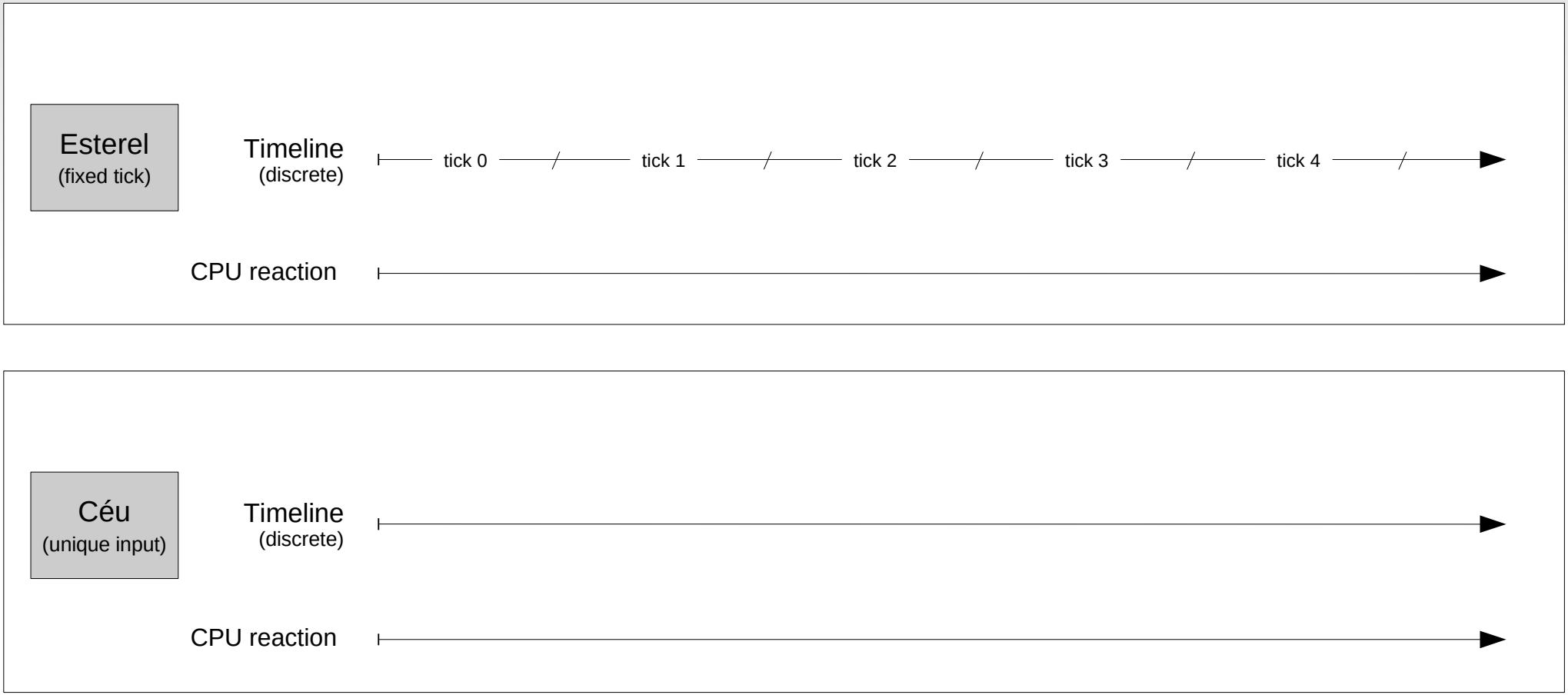

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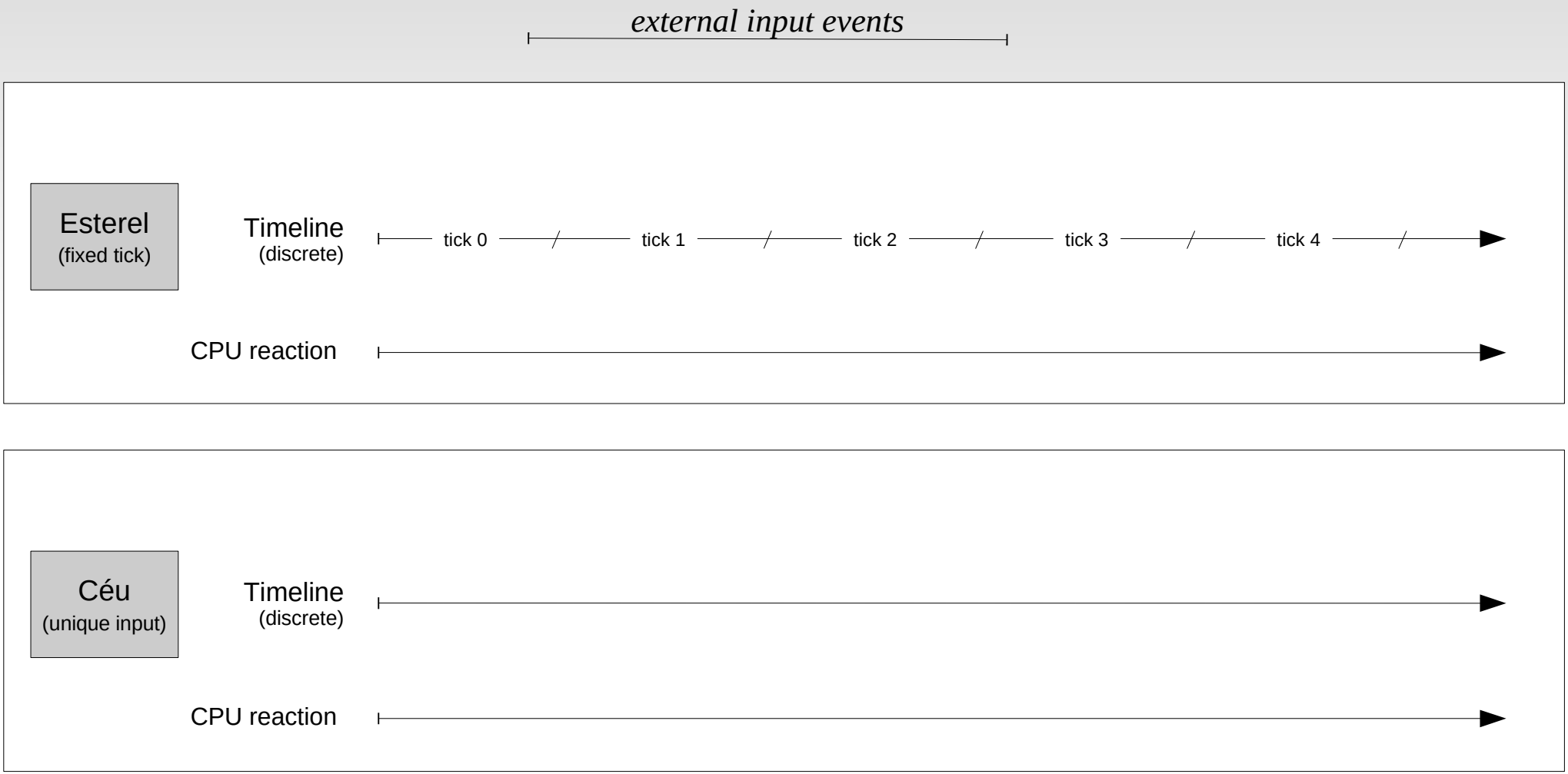

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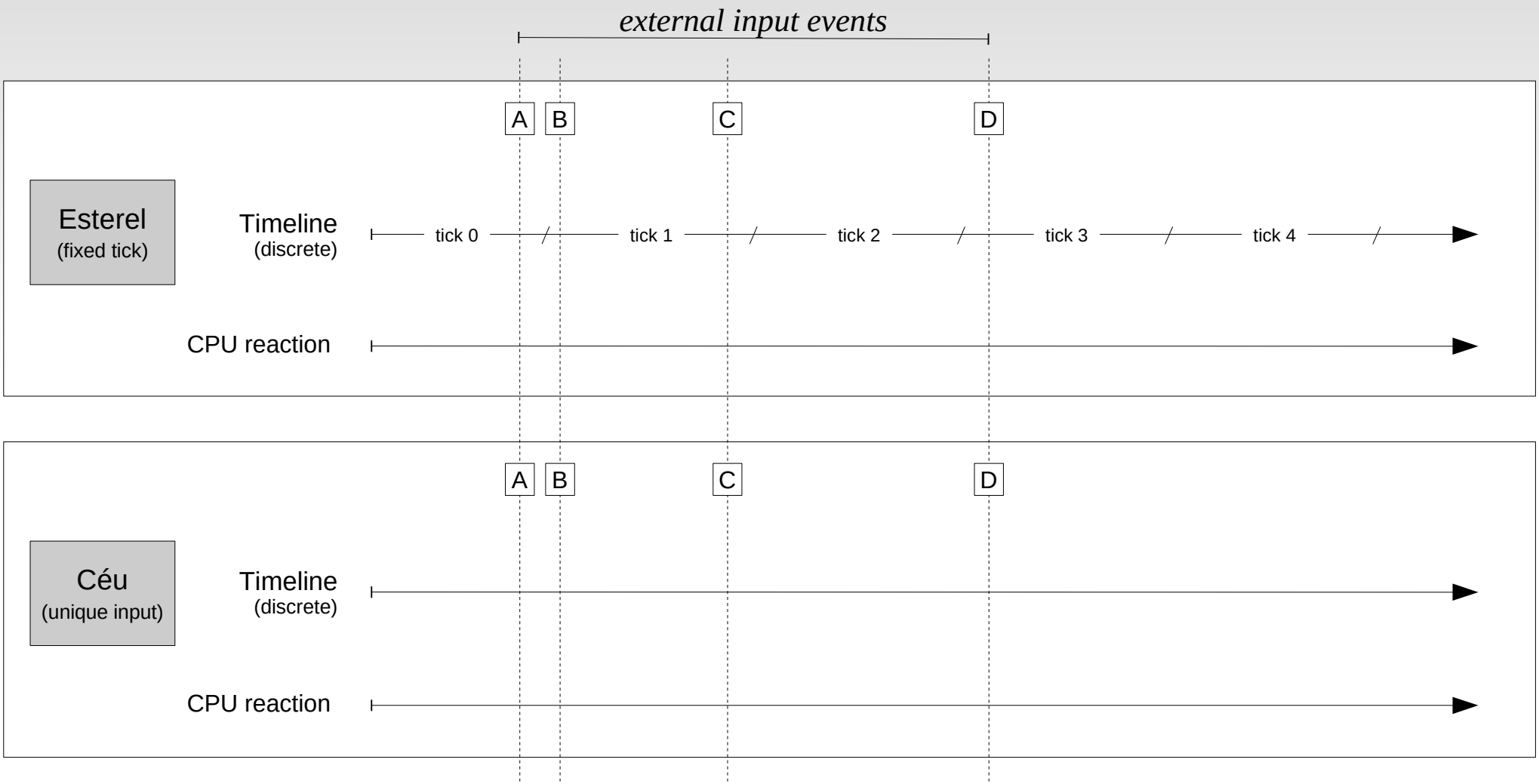

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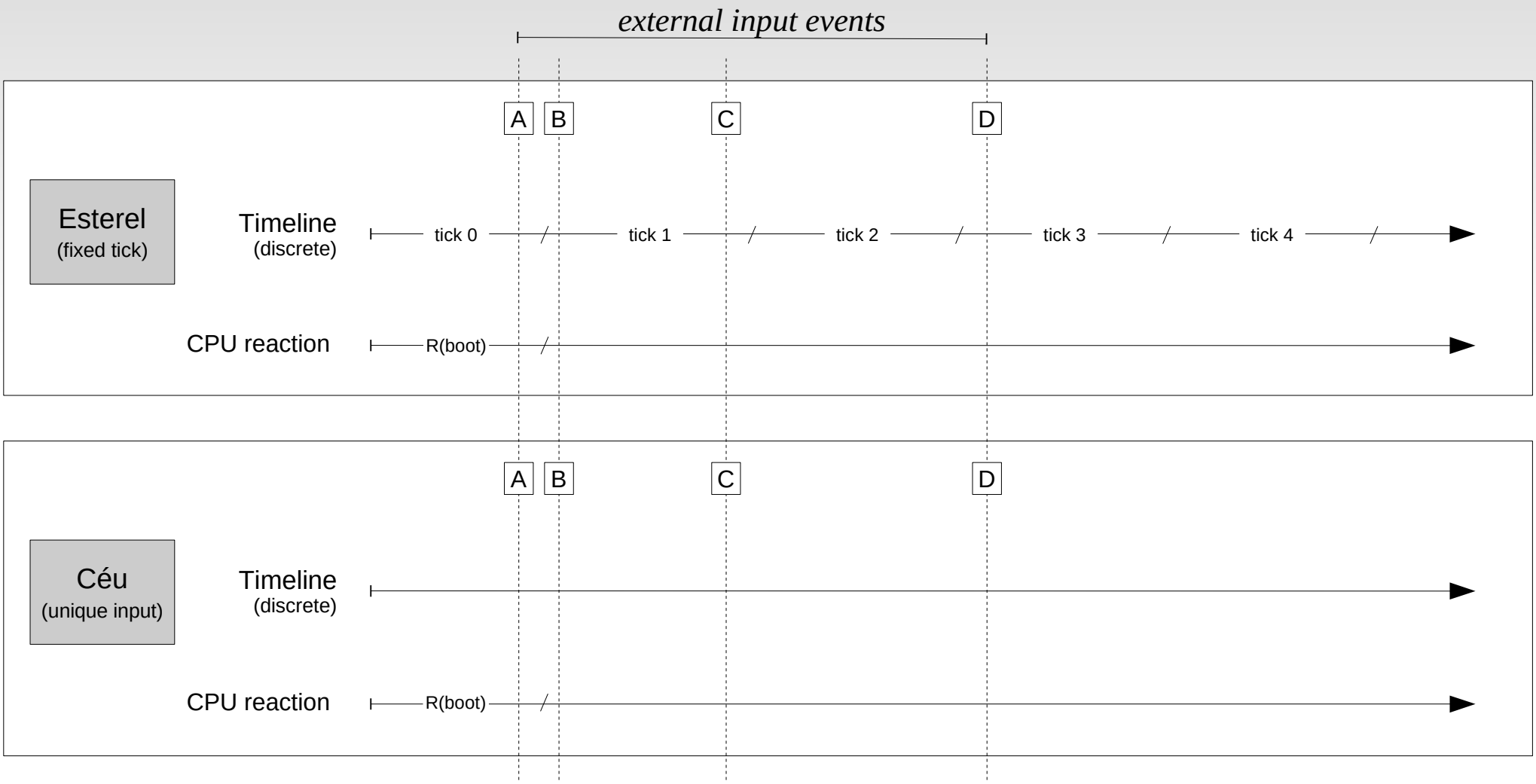

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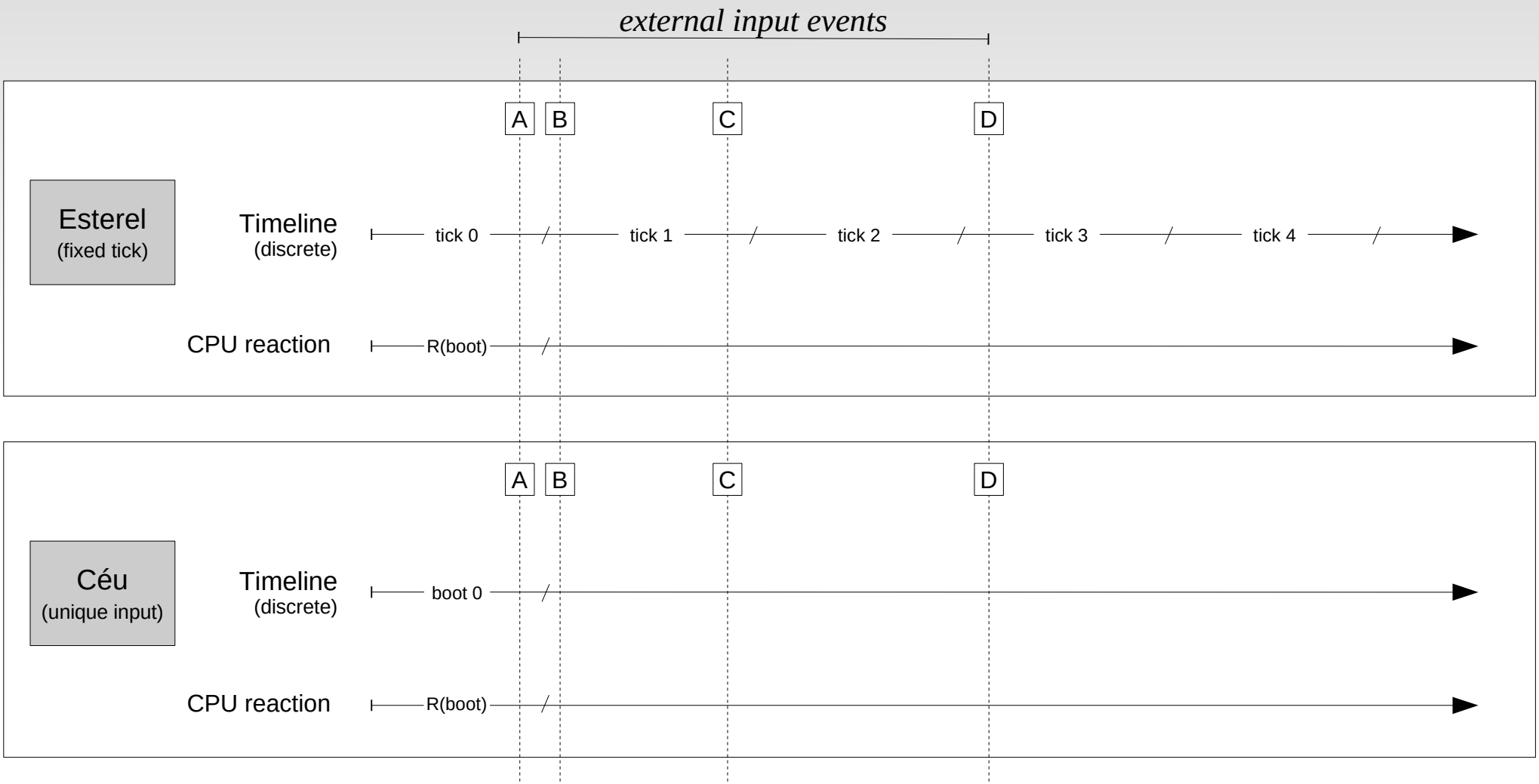

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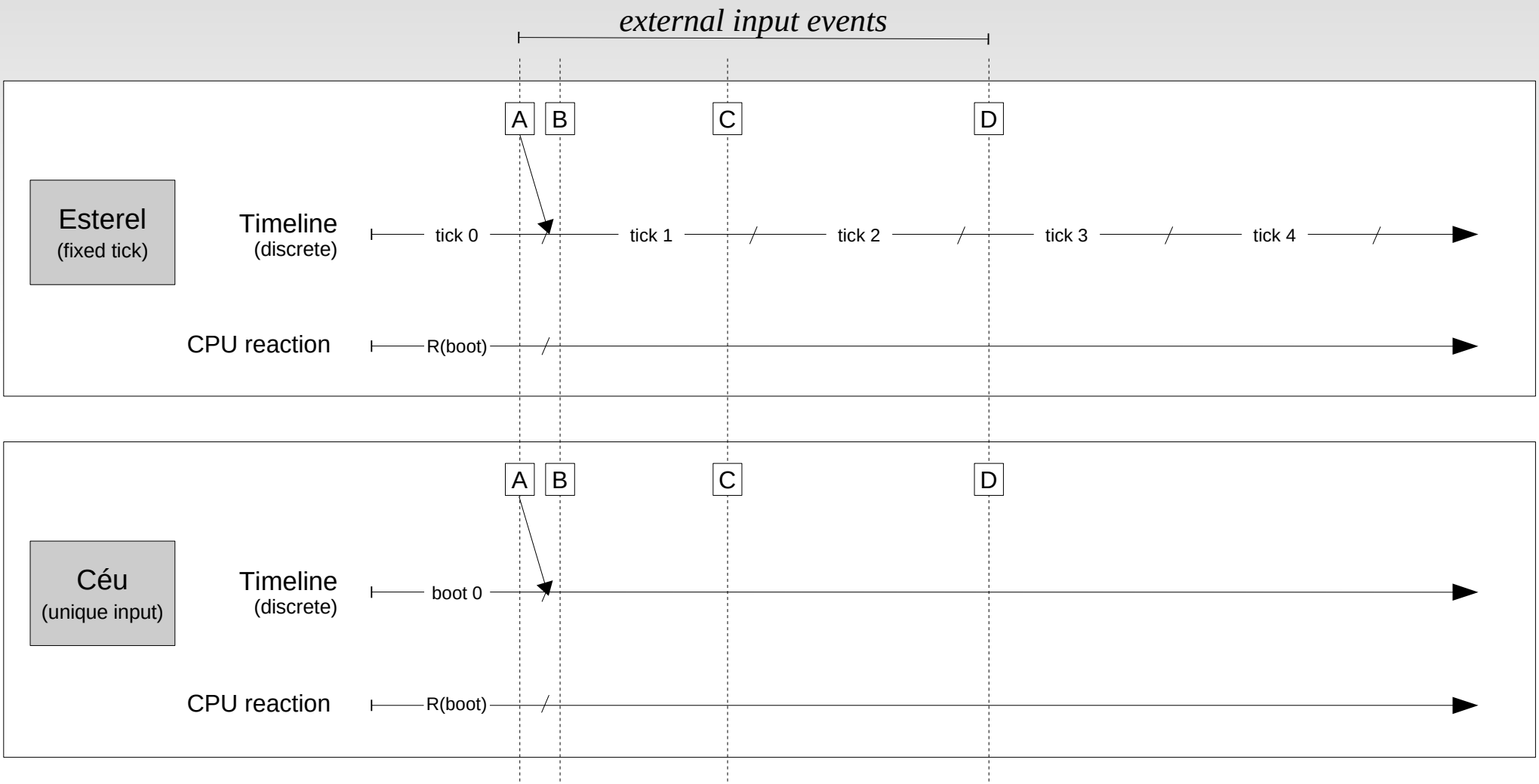

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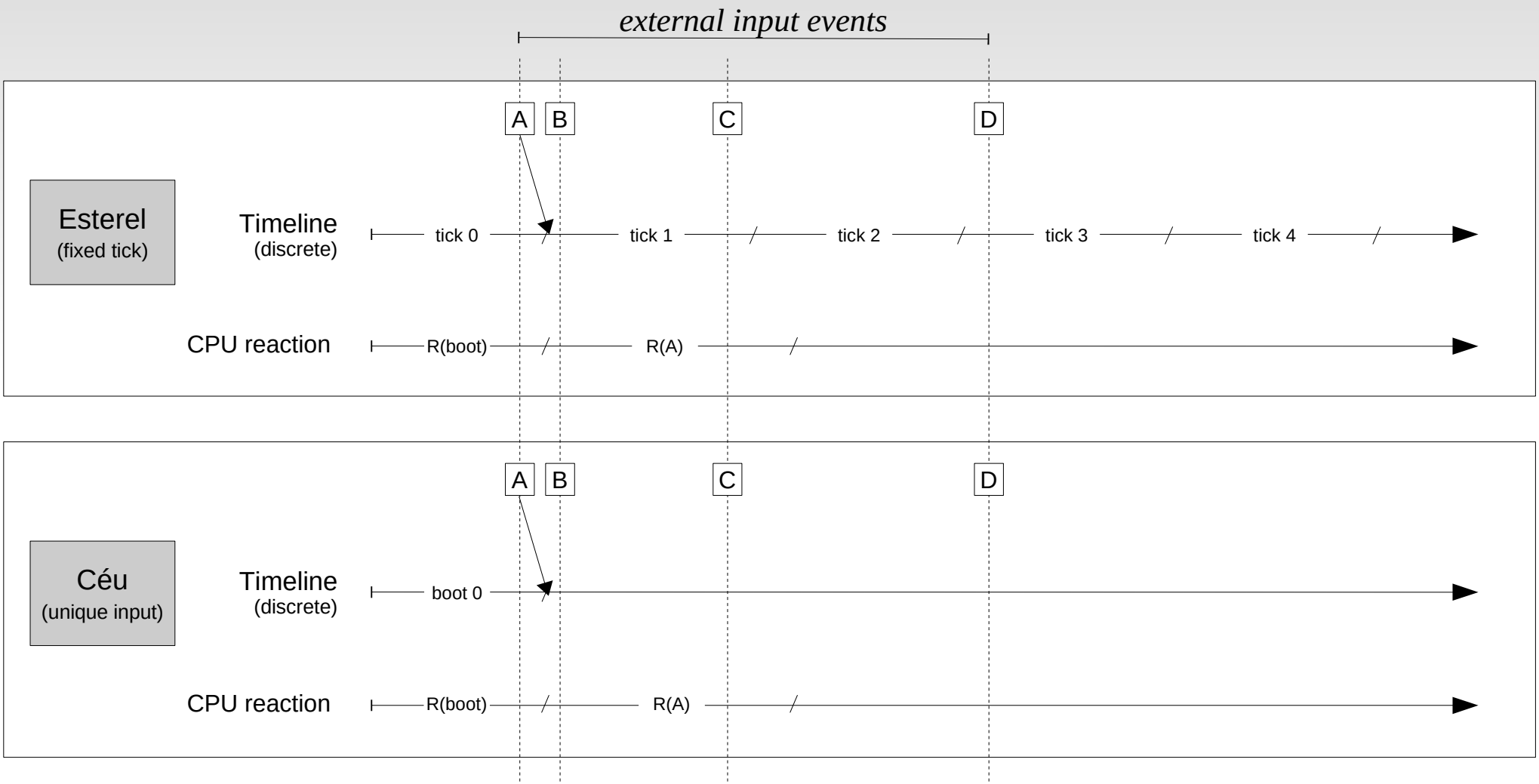

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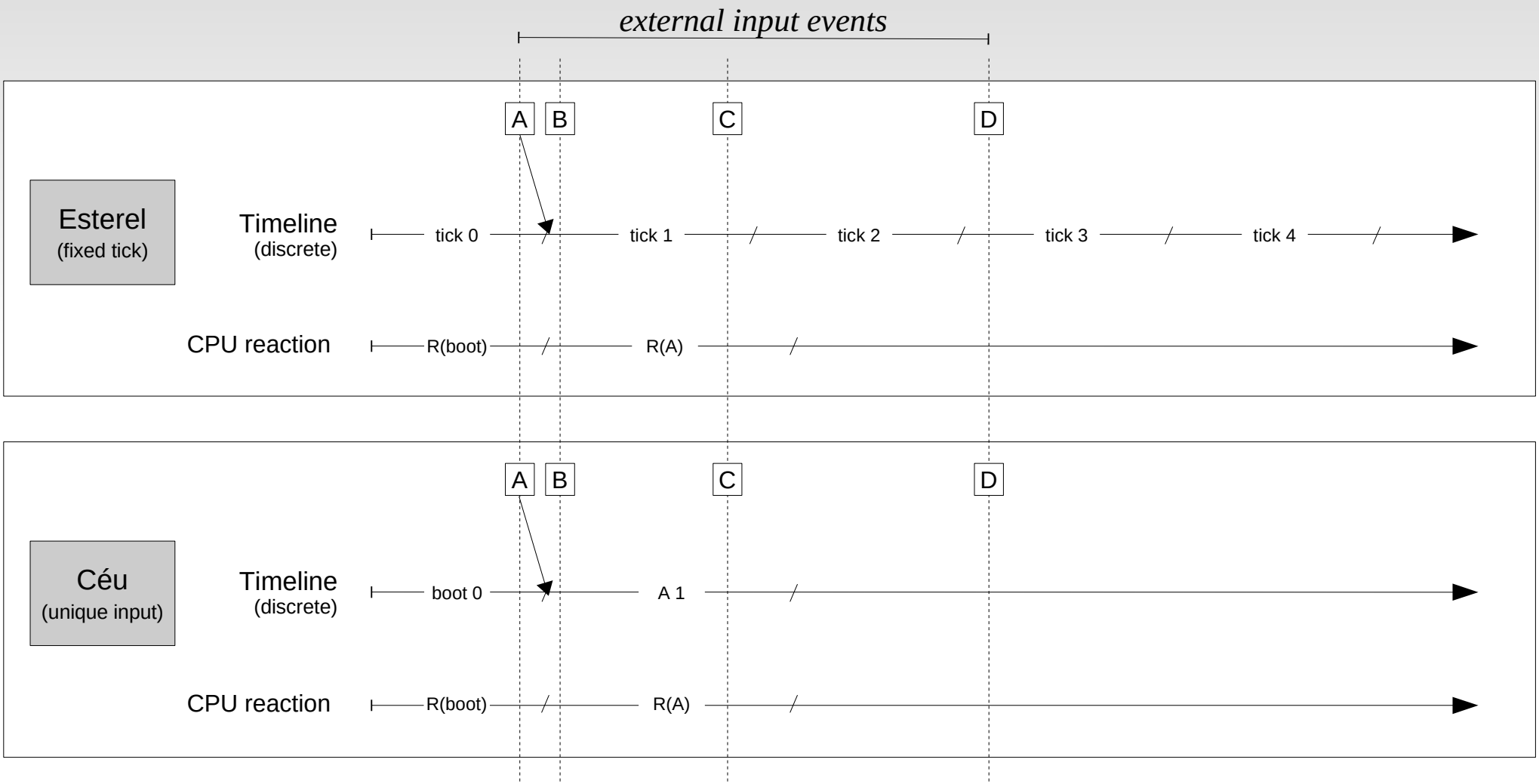

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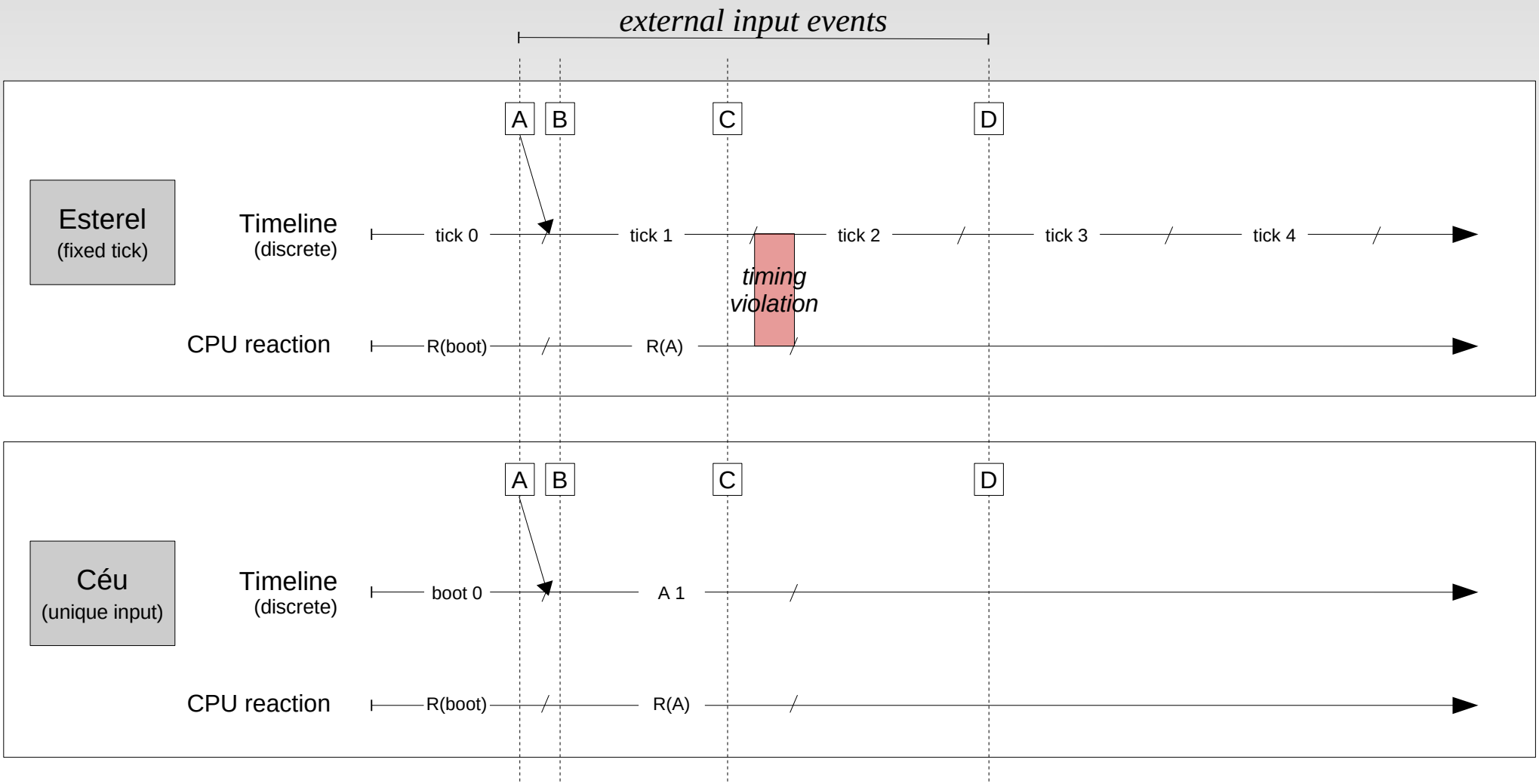

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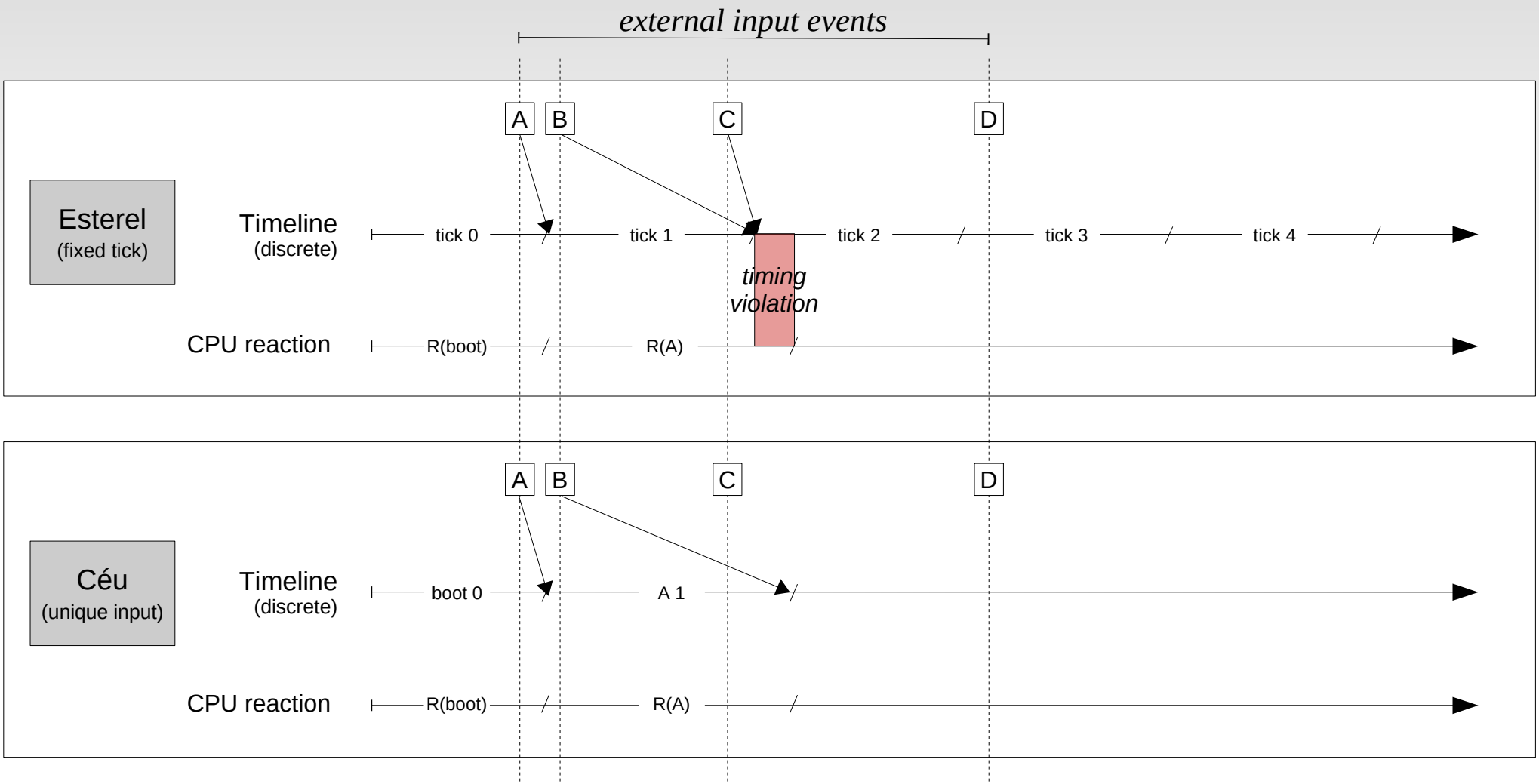

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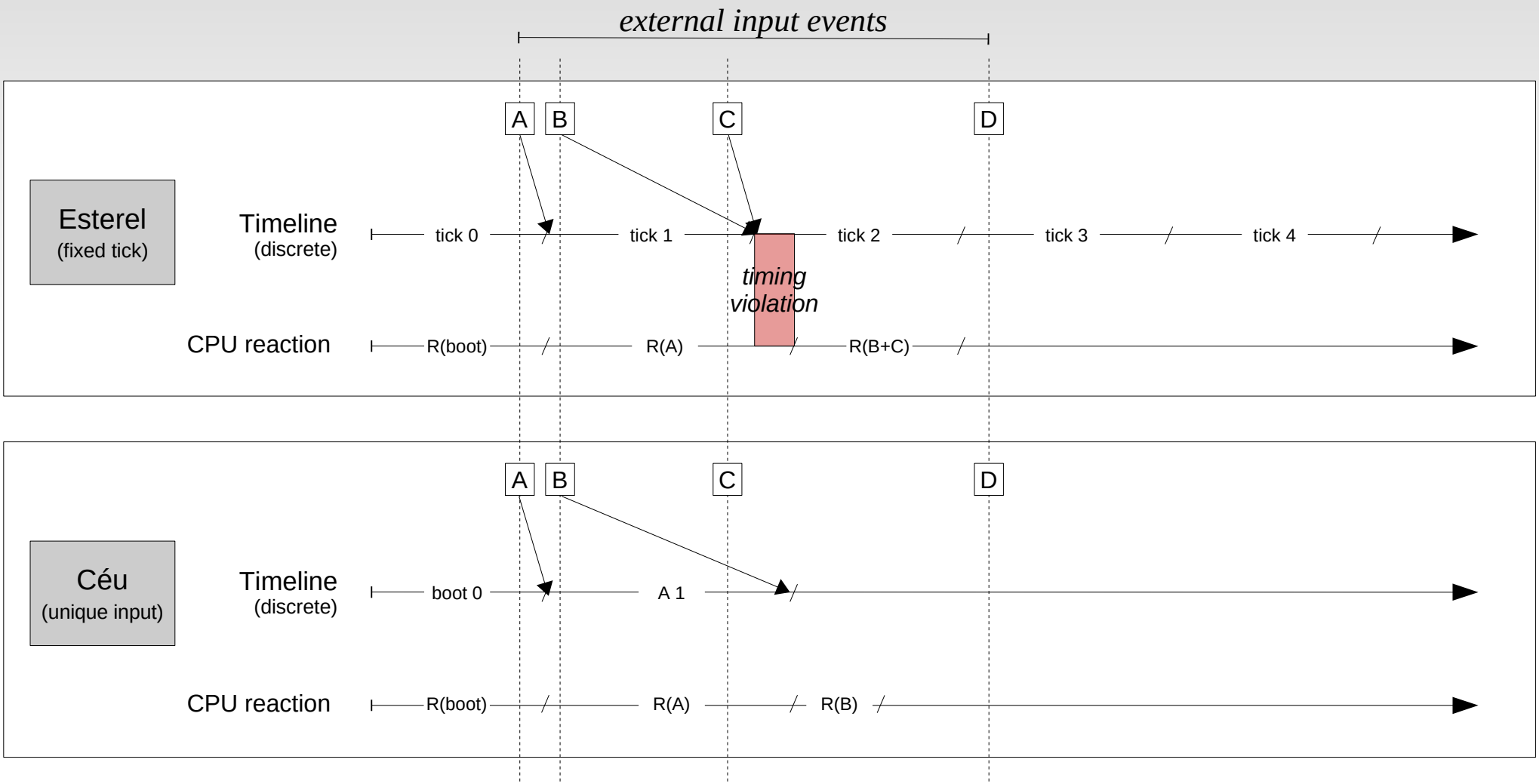

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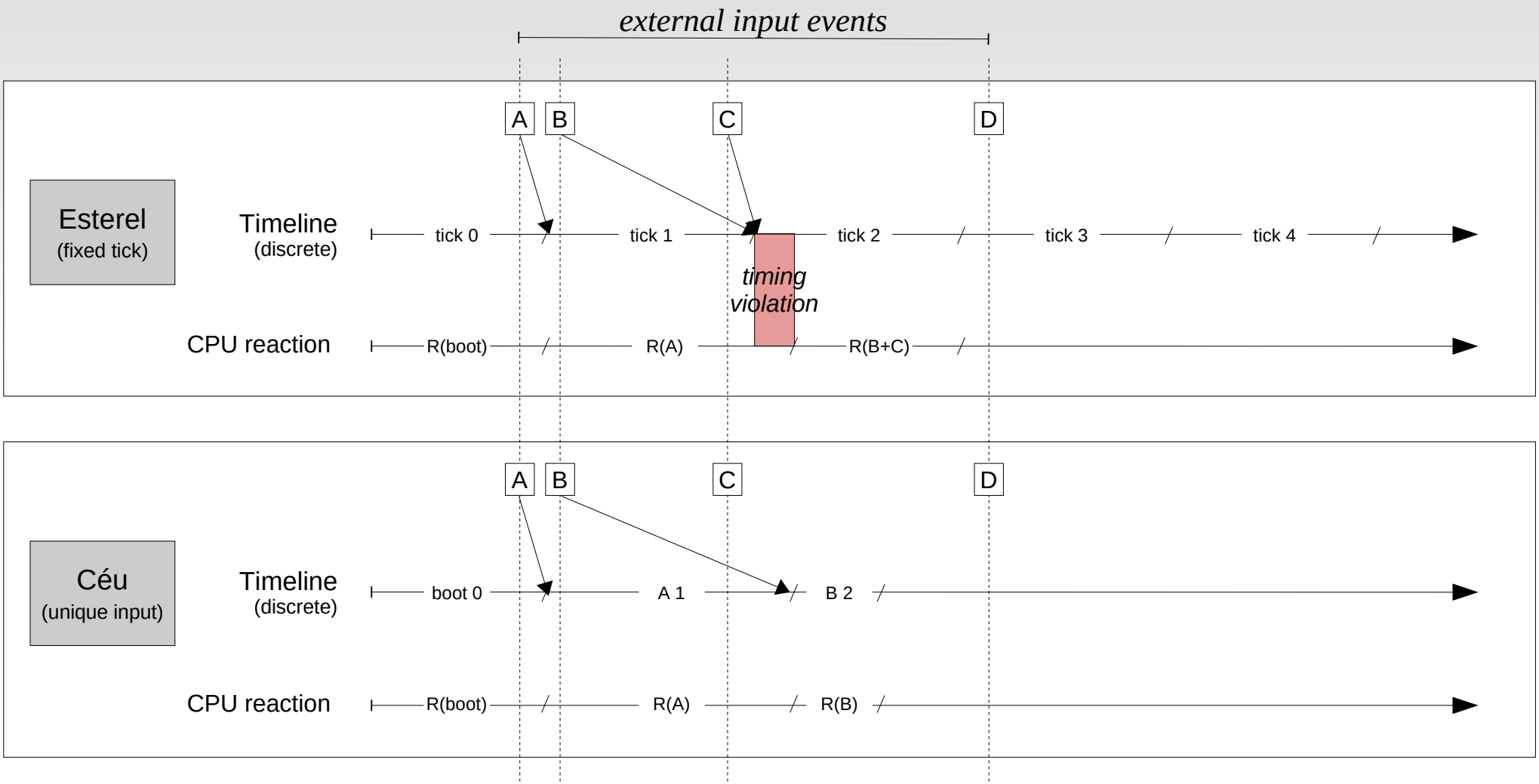

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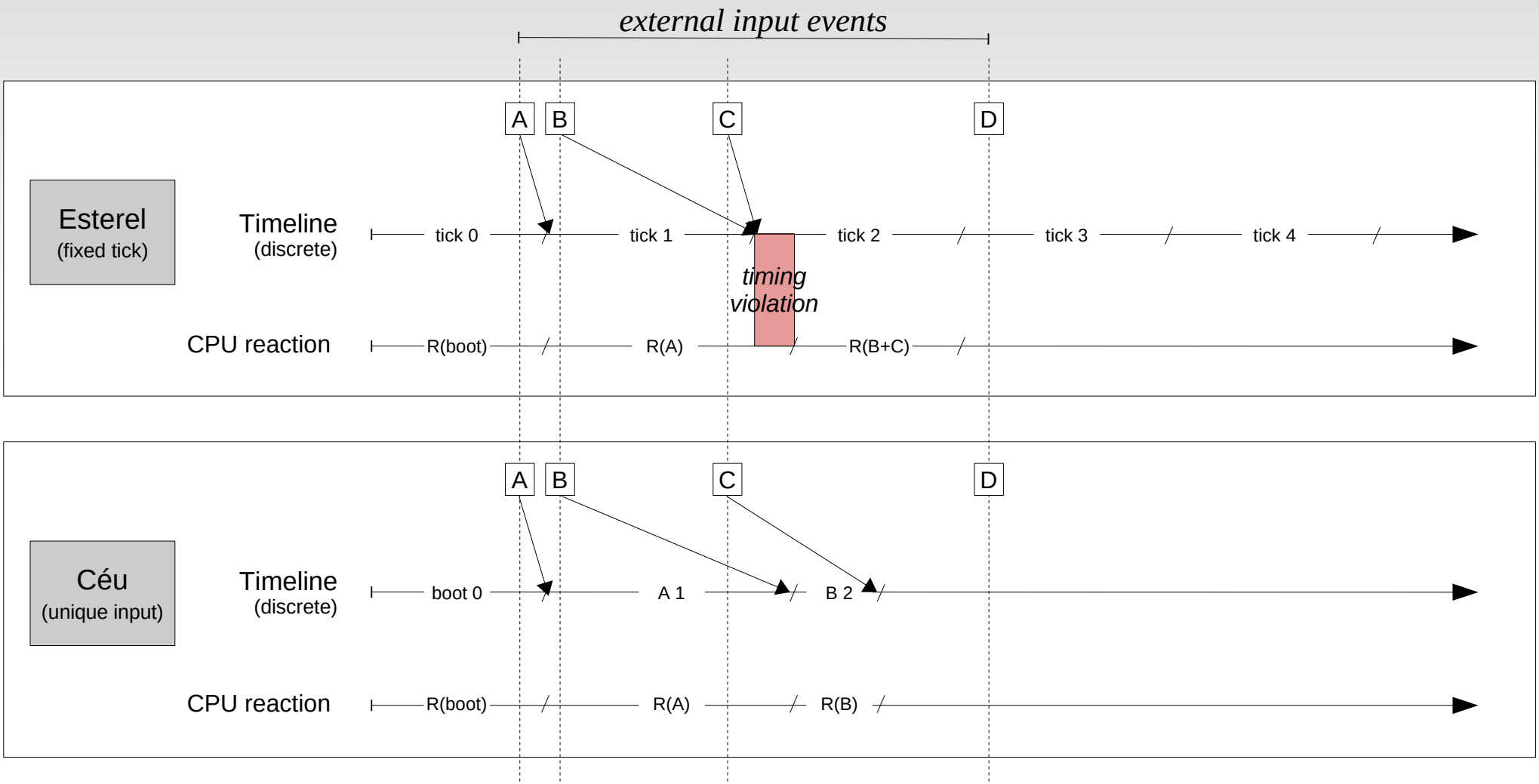

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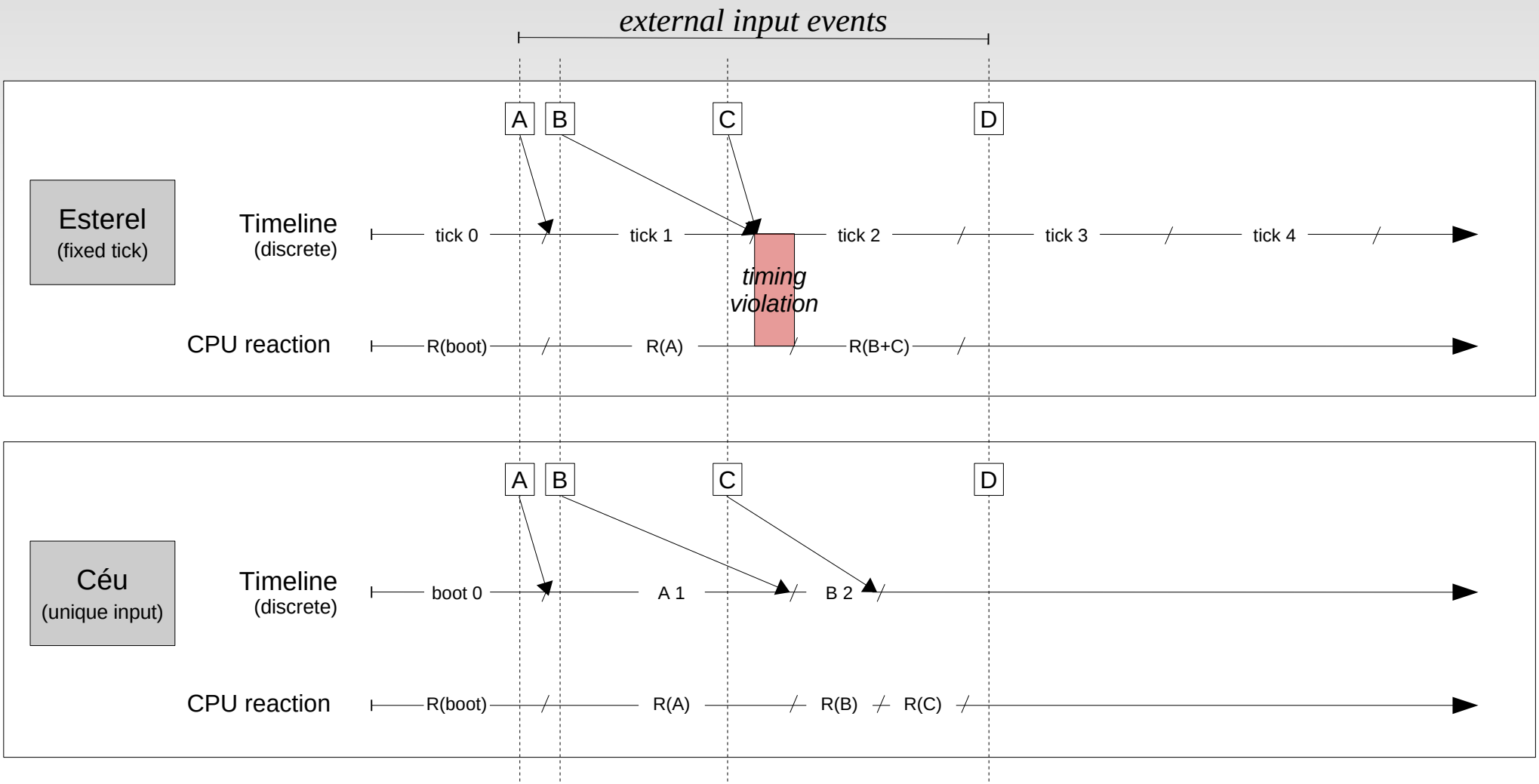

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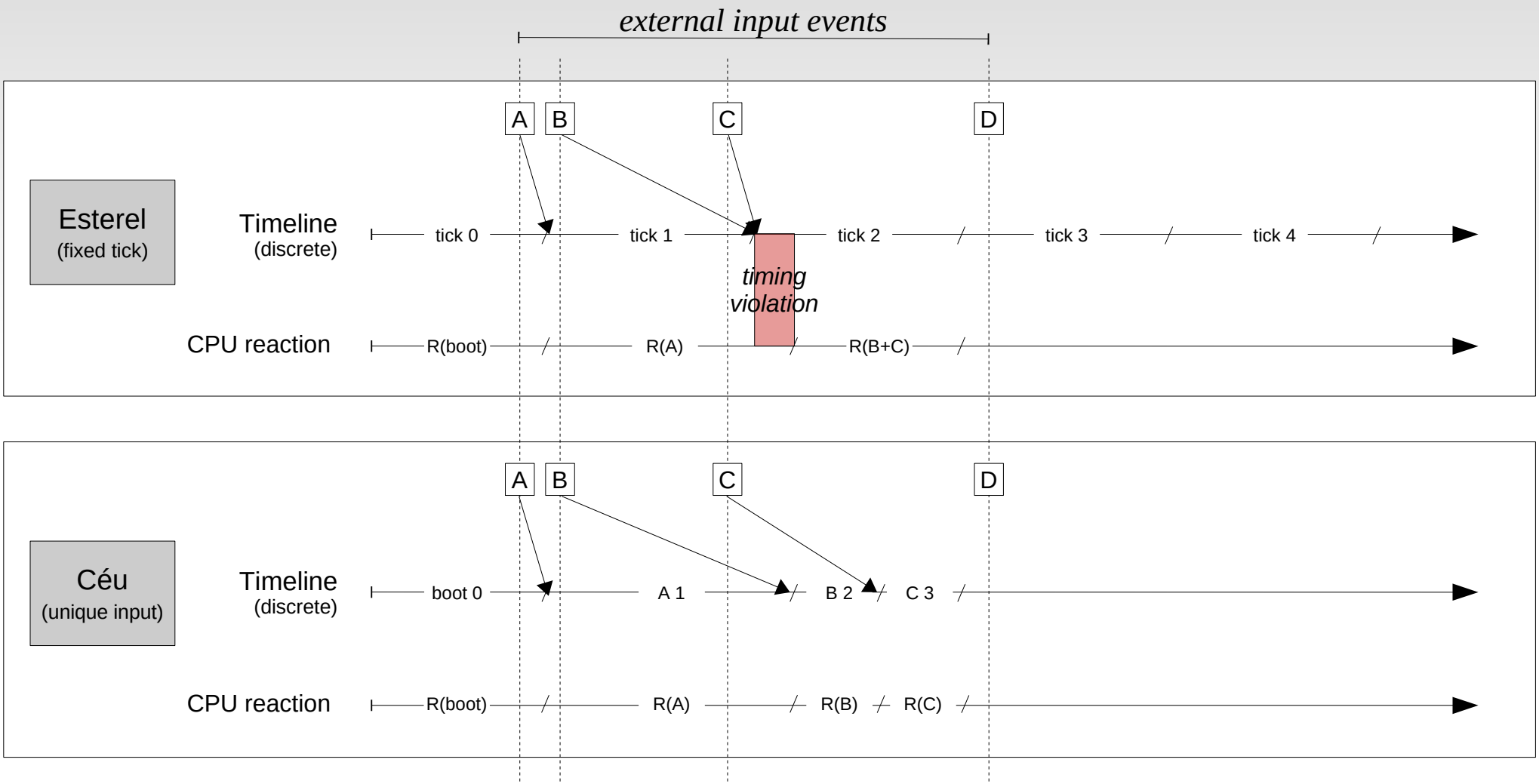

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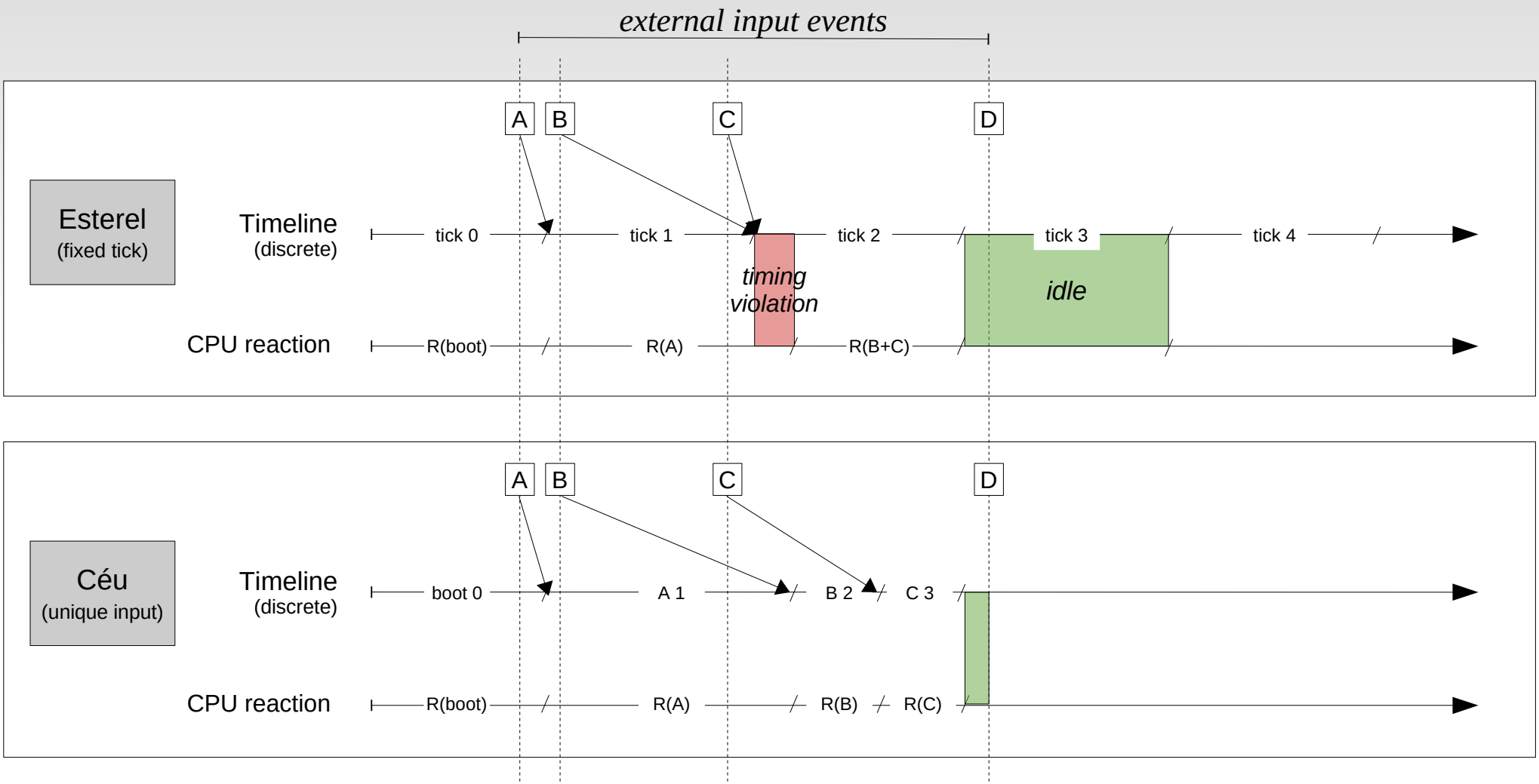

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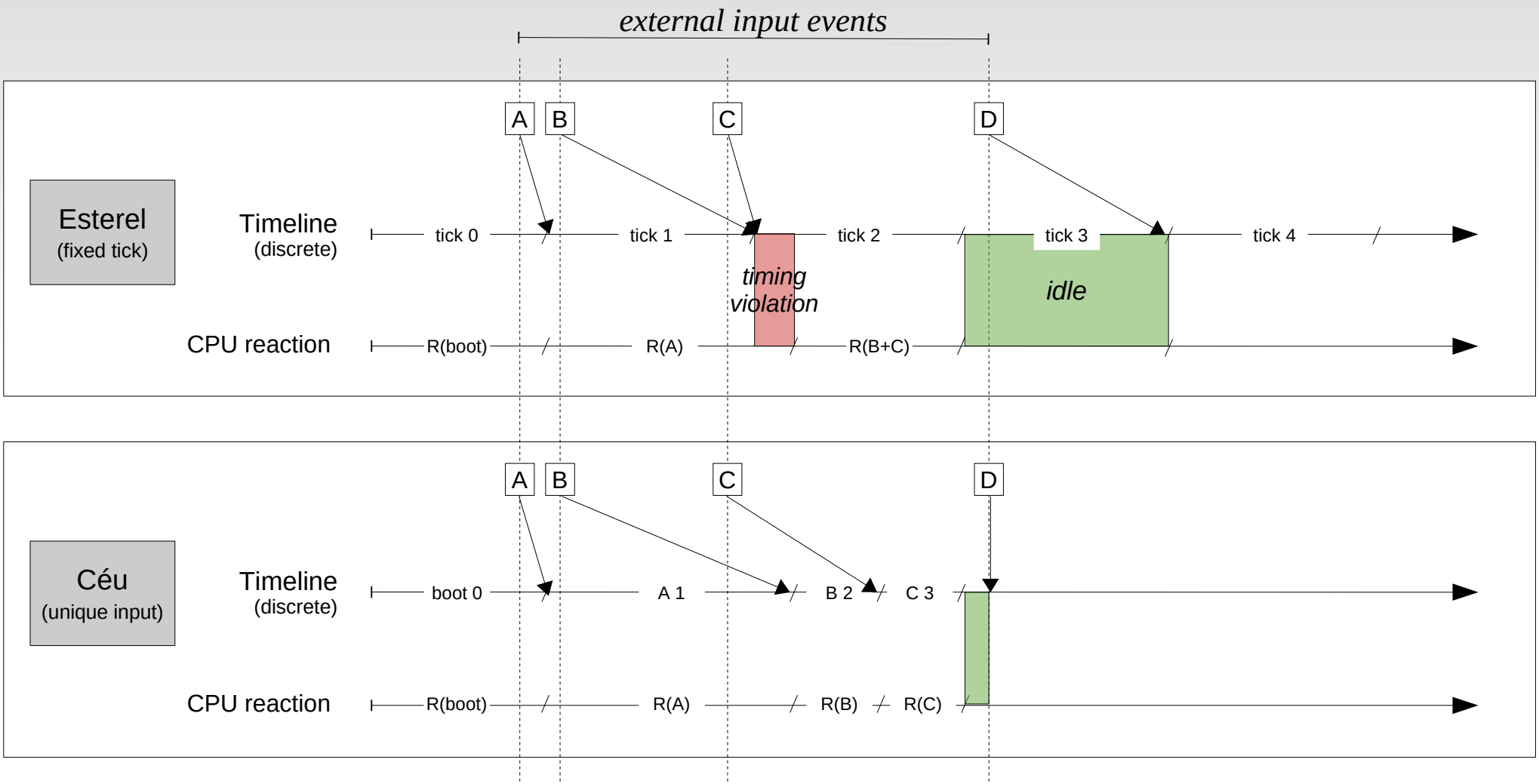

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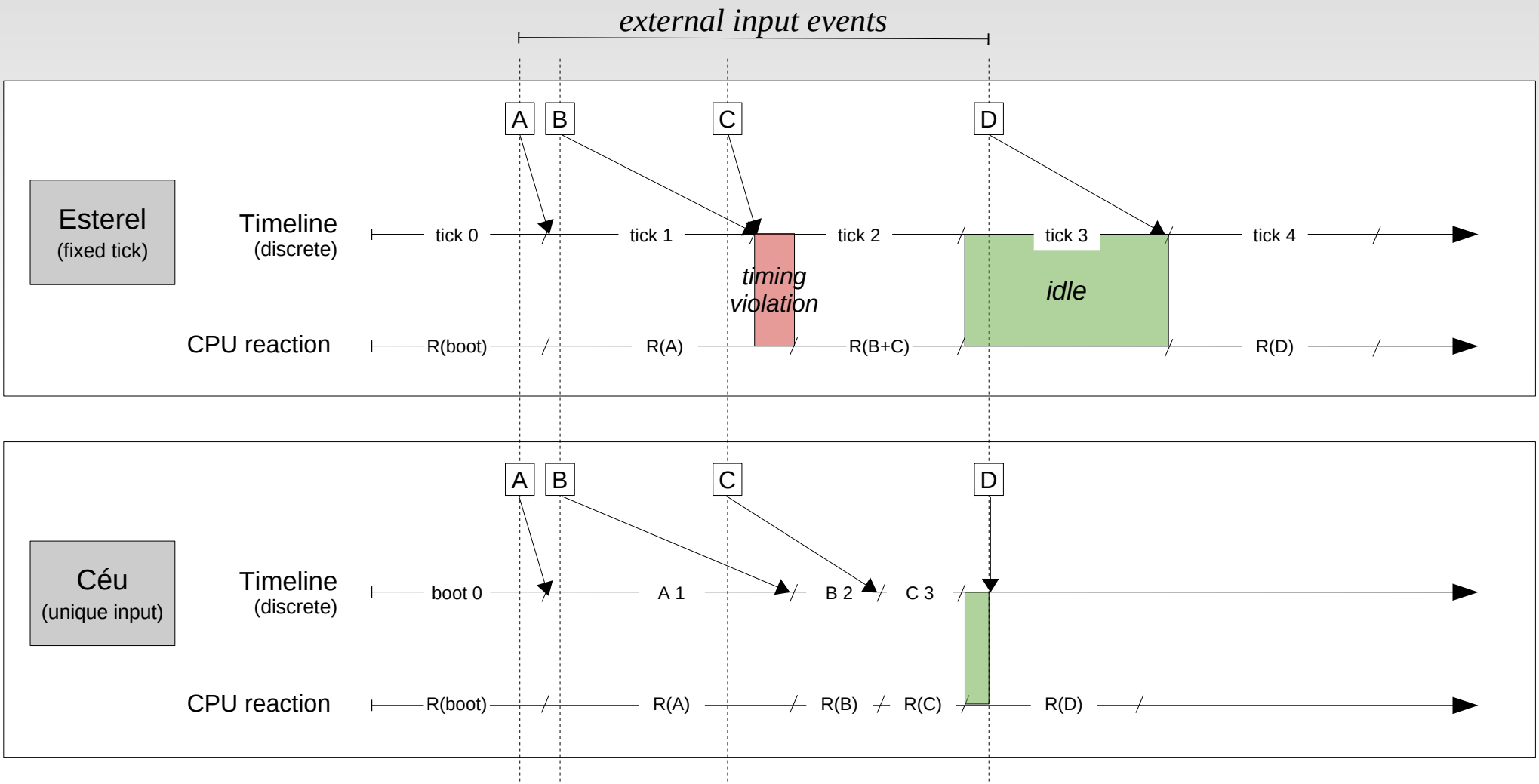

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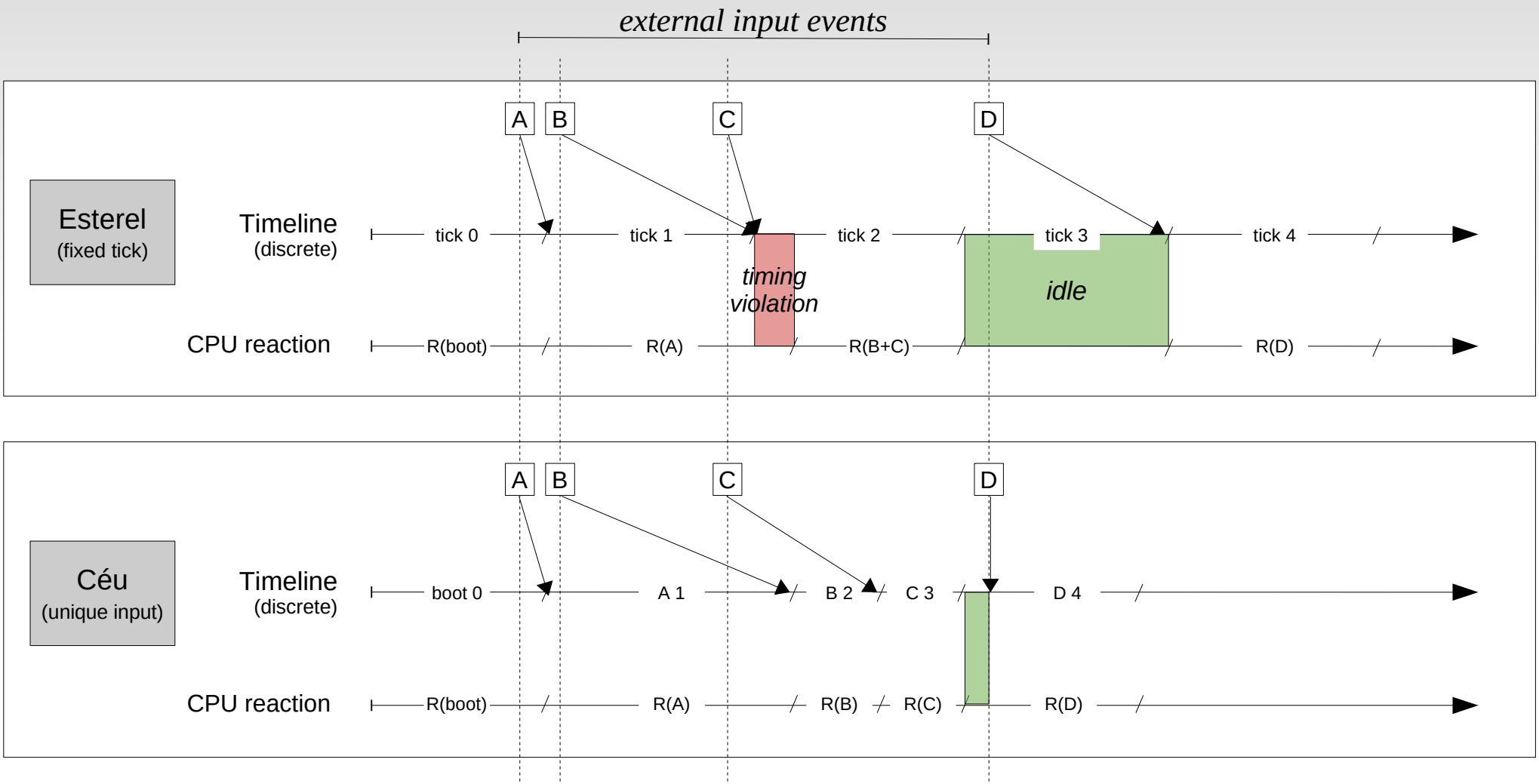

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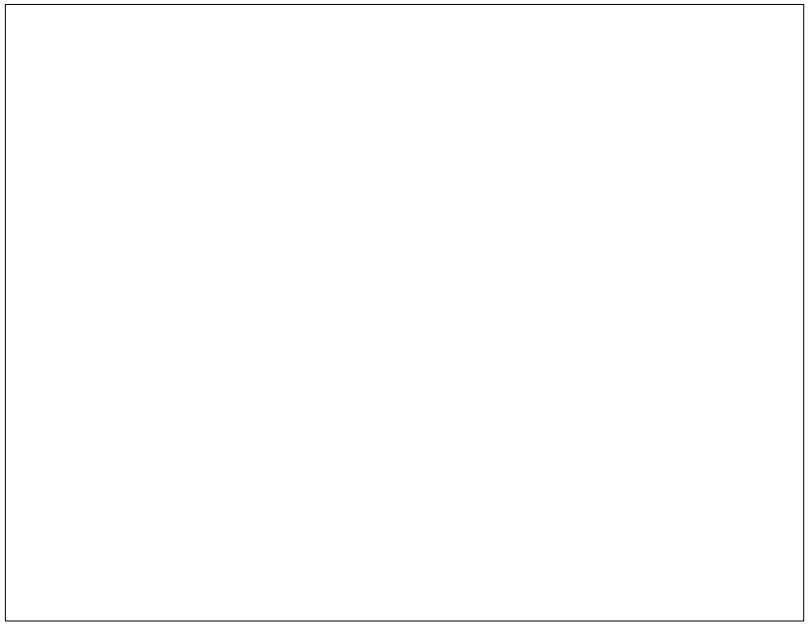
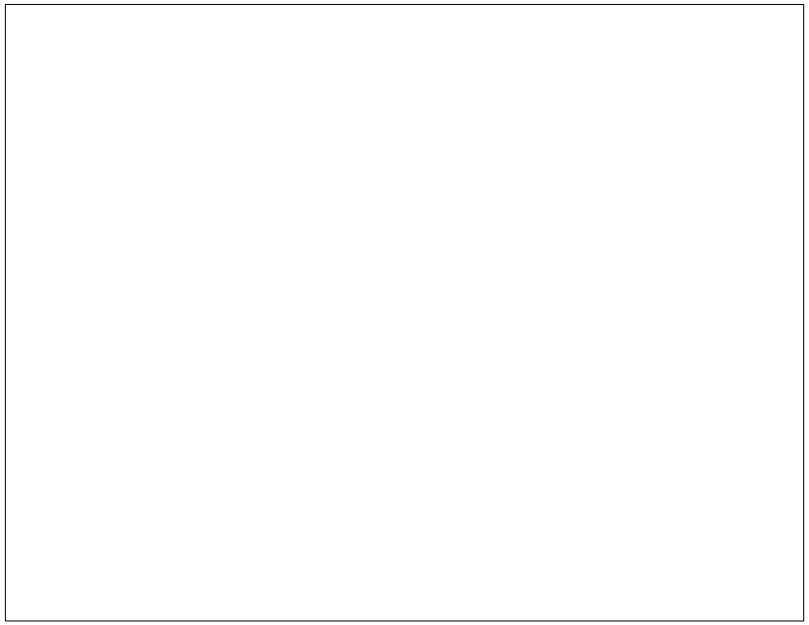


2. Internal Events

- Stack-based execution



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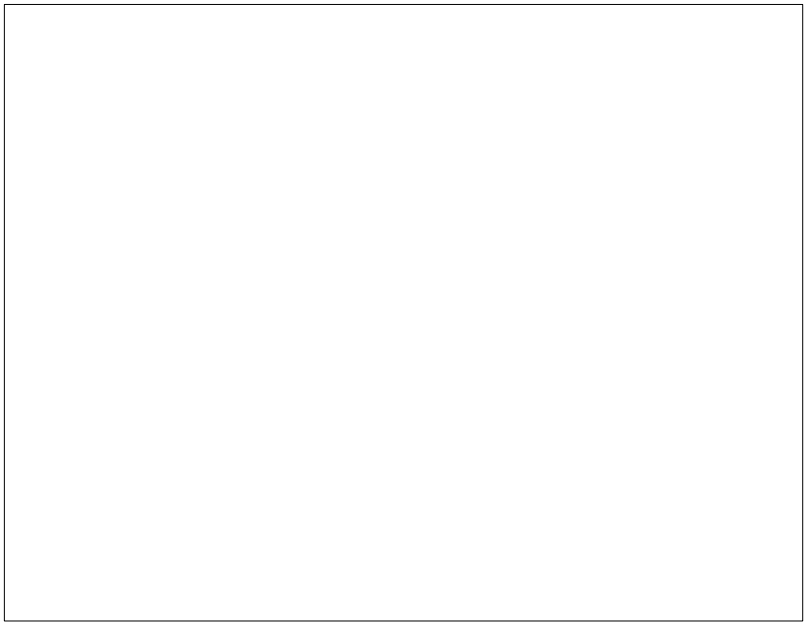
  - an **`emit`** stacks next statement → awakes awaiting trails in an *intra reaction*



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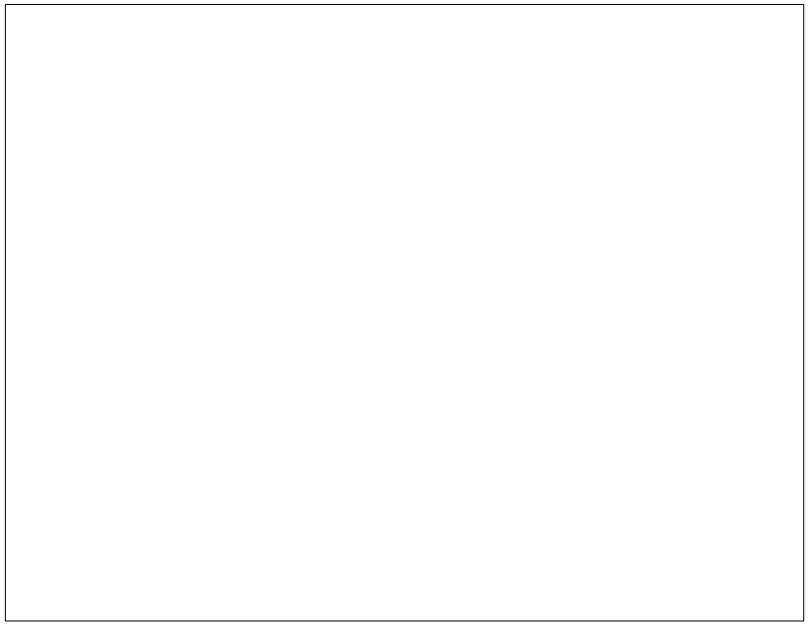

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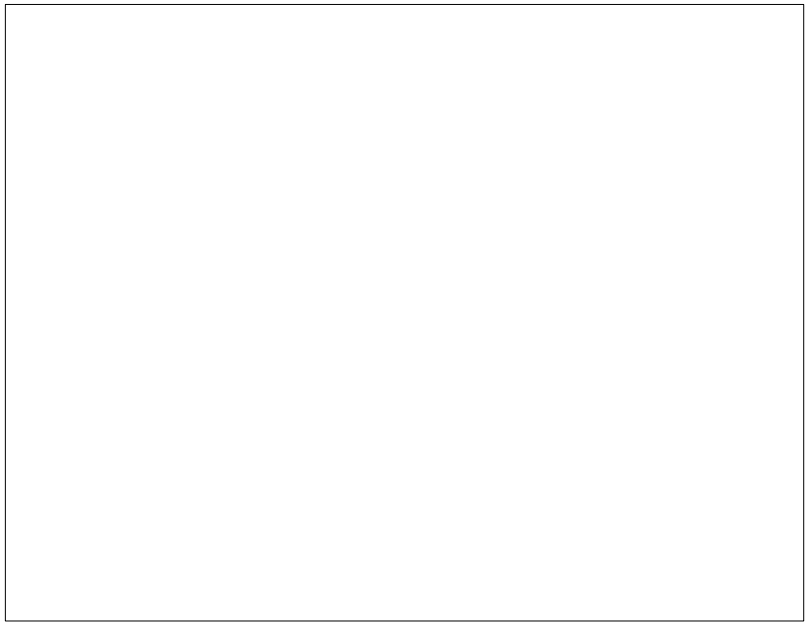

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```
event int* inc;
```

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```
event int* inc;
par/or do
```

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```
event int* inc;
par/or do
   loop do
      var int* p = await inc;
      *p = *p + 1;
   end
with
```

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```
event int* inc;
par/or do
   loop do
      var int* p = await inc;
      *p = *p + 1;
   end
with
   var int v = 1;
   <...>
   emit inc => &v;
   assert(v==2);
end
```

2. Internal Events

- Stack-based execution
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```
event int* inc;
par/or do
   loop do
      var int* p = await inc; 1
      *p = *p + 1;
   end
with
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   end
with
   var int v = 1;
   <...>
   emit inc => &v; 2
   assert(v==2);
end
```

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```
event int* inc;
par/or do
   loop do
      var int* p = await inc; (1)
      *p = *p + 1;
   end
with
   var int v = 1;
   <...>
   emit inc => &v; (2)
   assert(v==2);
end
```

stacked

2. Internal Events

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  - an **`emit`** stacks next statement → awakes awaiting trails in an *intra reaction*
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```
event int* inc;
par/or do
   loop do
      var int* p = await inc; (1)
      *p = *p + 1; (3)
   end
with
   var int v = 1;
   <...>
   emit inc => &v; (2)
   assert(v==2);
end
```

stacked

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- Stack-based execution
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```
event int* inc;
par/or do
   loop do
      var int* p = await inc;   (1) (4)
      *p = *p + 1;              (3)
   end
with
   var int v = 1;
   <...>
   emit inc => &v;              (2)
   assert(v==2);                    stacked
end
```

2. Internal Events

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   loop do
      var int* p = await inc; (1) (4)
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   end
with
   var int v = 1;
   <...>
   emit inc => &v; (2)
   assert(v==2); (5)
end
```

stacked

2. Internal Events

- Stack-based execution
  - an **`emit`** stacks next statement → awakes awaiting trails in an *intra reaction*
  - emits can nest (hence a stack)
- Like function calls
  - but richer: coroutines, resumable exceptions, reactive variables

```
event int* inc;
par/or do
   loop do
      var int* p = await inc; (1) (4)
      *p = *p + 1; (3)
   end
with
   var int v = 1;
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stacked

3. Internal Determinism

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- Esterel:

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  - *“if there is no control dependency, as in (call f1() || call f2()) , the order is unspecified and it would be an error to rely on it”*

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  - *“if there is no control dependency, as in (call f1() || call f2()) , the order is unspecified and it would be an error to rely on it”*
  - *“if a variable is written by some thread, then it can neither be read nor be written by concurrent threads”*

3. Internal Determinism

- Esterel:
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  - *“if a variable is written by some thread, then it can neither be read nor be written by concurrent threads”*
- Céu:

3. Internal Determinism

- Esterel:
  - *“if there is no control dependency, as in (call f1() || call f2()) , the order is unspecified and it would be an error to rely on it”*
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- Céu:
  - *“when multiple trails are active during the same reaction, they are scheduled in lexical order”*

3. Internal Determinism

- Esterel:
  - *"if there is no control dependency, as in (call f1() || call f2()) [1], the order is unspecified and it would be an error to rely on it"*
  - *"if a variable is written by some thread, then it can neither be read nor be written by concurrent threads"*
- Céu:
  - *"when multiple trails are active during the same reaction, they are scheduled in lexical order"*

3. Internal Determinism

- Esterel:
  - *“if there is no control dependency, as in (call f1() (1) || call f2() (2)) , the order is unspecified and it would be an error to rely on it”*
  - *“if a variable is written by some thread, then it can neither be read nor be written by concurrent threads”*
- Céu:
  - *“when multiple trails are active during the same reaction, they are scheduled in lexical order”*

3. Internal Determinism

- Esterel:
  - *"if there is no control dependency, as in (call f1() || call f2()) , the order is unspecified and it would be an error to rely on it"*
  - *"if a variable is written by some thread, then it can neither be read nor be written by concurrent threads"*
- Céu:
  - *"when multiple trails are active during the same reaction, they are scheduled in lexical order"*
  - pragmatic (e.g., `printf`, `redraw`), but fragile

3. Simple Static Checks

3. Simple Static Checks

```
input void A, B;
var int x = 1;
```

3. Simple Static Checks

```
input void A, B;
var int x = 1;
par/and do
```

3. Simple Static Checks

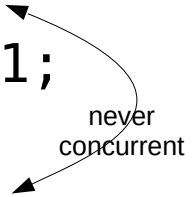
```
input void A, B;
var int x = 1;
par/and do
   await A;
   x = x + 1;
with
```

3. Simple Static Checks

```
input void A, B;
var int x = 1;
par/and do
   await A;
   x = x + 1;
with
   await B;
   x = x * 2;
end
```

3. Simple Static Checks

```
input void A, B;
var int x = 1;
par/and do
    await A;
    x = x + 1;
with
    await B;
    x = x * 2;
end
```



3. Simple Static Checks

```
input void A, B;
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par/and do
    await A;
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with
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end
```

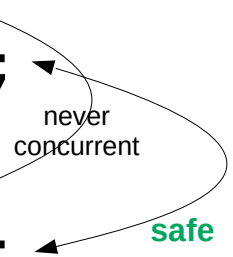

3. Simple Static Checks

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input void A, B;
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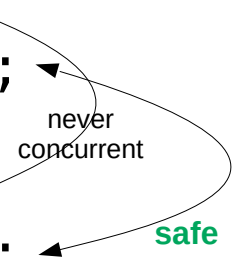
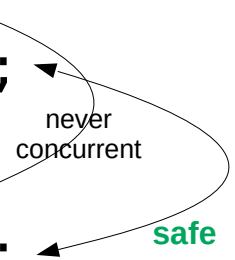
par/and do
    await A;
    x = x + 1;
with
    await B;
    x = x * 2;
end
```



3. Simple Static Checks

```
input void A, B;
var int x = 1;
par/and do
    await A;
    x = x + 1;
with
    await B;
    x = x * 2;
end
```




```
input void A;
var int y = 1;
```

3. Simple Static Checks

```
input void A, B;
var int x = 1;
par/and do
   await A;
   x = x + 1;
with
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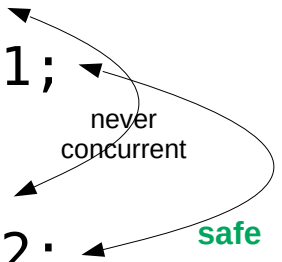
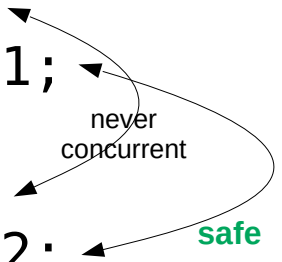
   x = x * 2;
end
```




```
input void A;
var int y = 1;
par/and do
```

3. Simple Static Checks

```
input void A, B;
var int x = 1;
par/and do
   await A;
   x = x + 1;
with
   await B;
   x = x * 2;
end
```




```
input void A;
var int y = 1;
par/and do
   await A;
   y = y + 1;
with
```

3. Simple Static Checks

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input void A, B;
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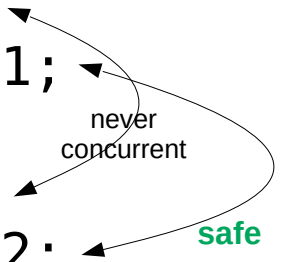



```
input void A;
var int y = 1;
par/and do
   await A;
   y = y + 1;
with
   await A;
   y = y * 2;
end
```

3. Simple Static Checks

```
input void A, B;
var int x = 1;
par/and do
   await A;
   x = x + 1;
with
   await B;
   x = x * 2;
end
```

never concurrent

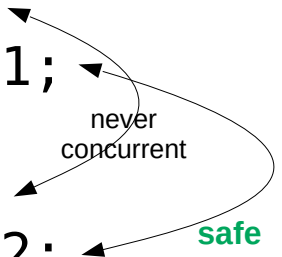
safe

```
input void A;
var int y = 1;
par/and do
   await A;
   y = y + 1;
with
   await A;
   y = y * 2;
end
```

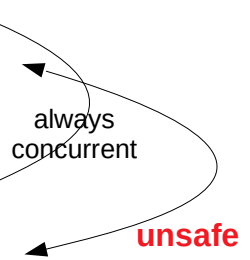
always concurrent

3. Simple Static Checks

```
input void A, B;
var int x = 1;
par/and do
   await A;
   x = x + 1;
with
   await B;
   x = x * 2;
end
```




```
input void A;
var int y = 1;
par/and do
   await A;
   y = y + 1;
with
   await A;
   y = y * 2;
end
```



3. Simple Static Checks

```
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var int x = 1;
par/and do
   await A;
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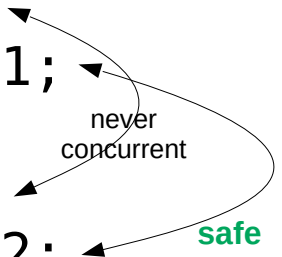
end
```

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end
```
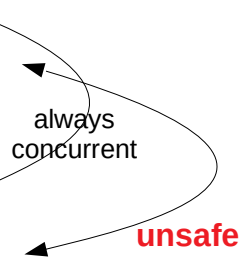
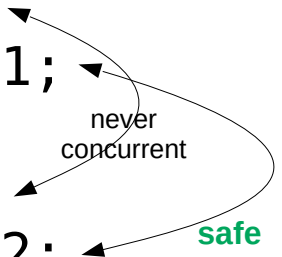



- Static checks

3. Simple Static Checks

```
input void A, B;
var int x = 1;
par/and do
   await A;
   x = x + 1;
with
   await B;
   x = x * 2;
end
```

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   y = y + 1;
with
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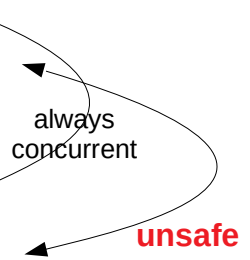
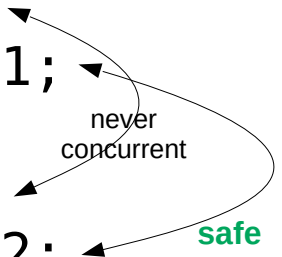
end
```



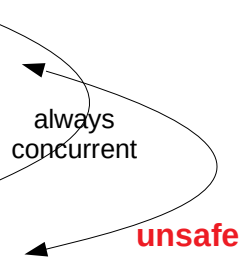
- Static checks
  - Level 0: both are refused

3. Simple Static Checks

```
input void A, B;
var int x = 1;
par/and do
   await A;
   x = x + 1;
with
   await B;
   x = x * 2;
end
```



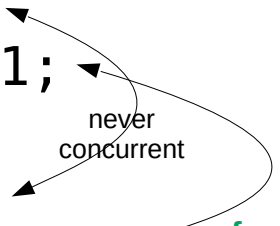

```
input void A;
var int y = 1;
par/and do
   await A;
   y = y + 1;
with
   await A;
   y = y * 2;
end
```



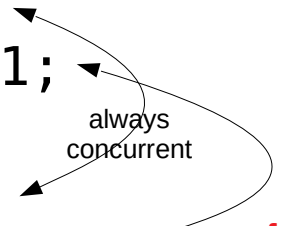
- Static checks
  - Level 0: both are refused
  - Level 1: unsafe is refused

3. Simple Static Checks

```
input void A, B;
var int x = 1;
par/and do
   await A;
   x = x + 1;
with
   await B;
   x = x * 2;
end
```



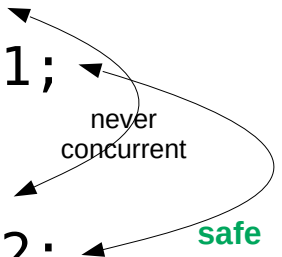

```
input void A;
var int y = 1;
par/and do
   await A;
   y = y + 1;
with
   await A;
   y = y * 2;
end
```



- Static checks
  - Level 0: both are refused
  - Level 1: unsafe is refused
  - Level 2: both are accepted

3. Simple Static Checks

```
input void A, B;
var int x = 1;
par/and do
   await A;
   x = x + 1;
with
   await B;
   x = x * 2;
end
```

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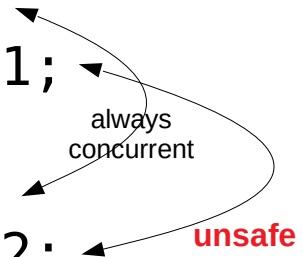

- Static checks
  - Level 0: both are refused
  - Level 1: unsafe is refused
  - Level 2: both are accepted
- Possible because of uniqueness of inputs

3. Simple Static Checks

```
input void A, B;
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with
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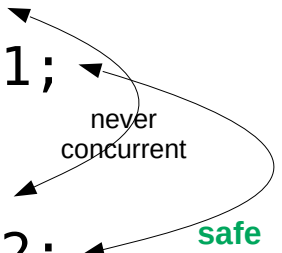


```
input void A;
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   y = y + 1;
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   await A;
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end
```
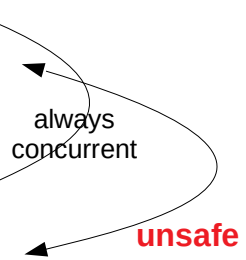
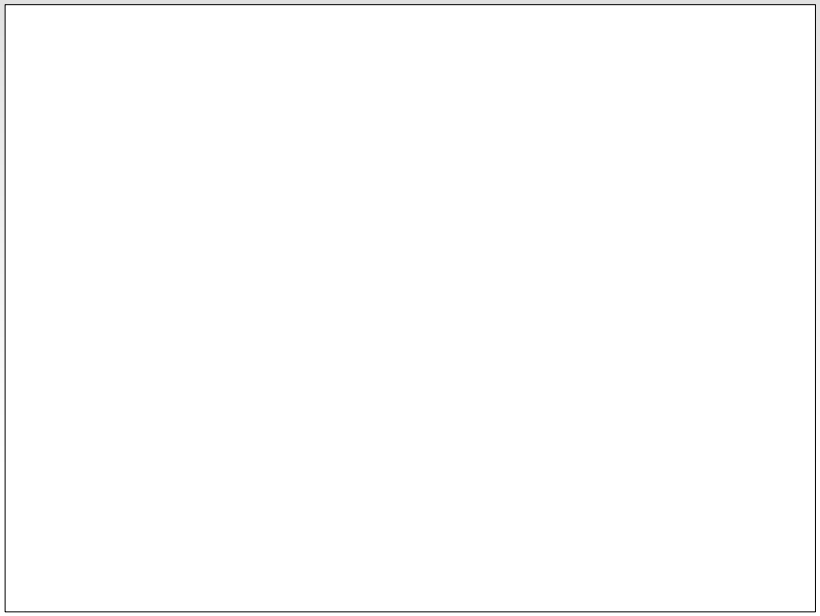



- Static checks
  - Level 0: both are refused
  - Level 1: unsafe is refused
  - Level 2: both are accepted
- Possible because of uniqueness of inputs
- Do not affect the semantics

4. Safe Integration with C



4. Safe Integration with C

```
native do
   #define NUM 10
   void f  (void)  { <...> }
   void g  (int v) { <...> }
   int  id (int v) { <...> }
end
```

4. Safe Integration with C

```
native do
   #define NUM 10
   void f  (void)  { <...> }
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   int  id (int v) { <...> }
end

par/and do
   _f();
with
   _g(_id(_NUM));
end
```

4. Safe Integration with C

```
native do
   #define NUM 10
   void f  (void)  { <...> }
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par/and do
   _f();
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- Trackable identifiers `_´ (*C hat*)

4. Safe Integration with C

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native do
   #define NUM 10
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- Trackable identifiers `_´ (*C hat*)
- Assumes all identifiers are conflicting

4. Safe Integration with C

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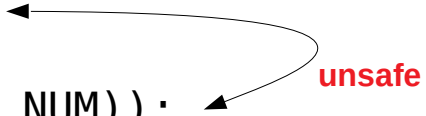

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4. Safe Integration with C

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   #define NUM 10
   void f  (void)  { <...> }
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end

par/and do
   _f();
with
   _g(_id(_NUM));
end
```

- Trackable identifiers `_´ (*C hat*)
- Assumes all identifiers are conflicting
- Annotations to eliminate conflicts

4. Safe Integration with C

```
native do
   #define NUM 10
   void f  (void)  { <...> }
   void g  (int v) { <...> }
   int  id (int v) { <...> }
end

par/and do
   _f();
with
   _g(_id(_NUM));
end
```

unsafe

```
native @const _NUM;
```

- Trackable identifiers `_´ (*C hat*)
- Assumes all identifiers are conflicting
- Annotations to eliminate conflicts

4. Safe Integration with C

```
native do
   #define NUM 10
   void f  (void)  { <...> }
   void g  (int v) { <...> }
   int  id (int v) { <...> }
end

par/and do
   _f();
with
   _g(_id(_NUM));
end
```

unsafe

```
native @const _NUM;
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- Trackable identifiers `_´ (*C hat*)
- Assumes all identifiers are conflicting
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4. Safe Integration with C

```
native do
   #define NUM 10
   void f  (void)  { <...> }
   void g  (int v) { <...> }
   int  id (int v) { <...> }
end

par/and do
   _f();
with
   _g(_id(_NUM));
end
```

unsafe

```
native @const _NUM;
native @pure  _id();
```

- Trackable identifiers `_´ (*C hat*)
- Assumes all identifiers are conflicting
- Annotations to eliminate conflicts

4. Safe Integration with C

```
native do
   #define NUM 10
   void f  (void)  { <...> }
   void g  (int v) { <...> }
   int  id (int v) { <...> }
end

par/and do
   _f();
with
   _g(_id(_NUM));
end
```

unsafe

```
native @const _NUM;
native @pure  _id();
```

- Trackable identifiers `_´ (*C hat*)
- Assumes all identifiers are conflicting
- Annotations to eliminate conflicts

4. Safe Integration with C

```
native do
   #define NUM 10
   void f  (void)  { <...> }
   void g  (int v) { <...> }
   int  id (int v) { <...> }
end

par/and do
   _f();
with
   _g(_id(_NUM));
end
```

unsafe

```
native @const _NUM;
native @pure  _id();
native @safe  _f() with _g();
```

- Trackable identifiers `_´ (*C hat*)
- Assumes all identifiers are conflicting
- Annotations to eliminate conflicts

4. Safe Integration with C

```
native do
   #define NUM 10
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   _f();
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   _g(_id(_NUM));
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unsafe

```
native @const _NUM;
native @pure  _id();
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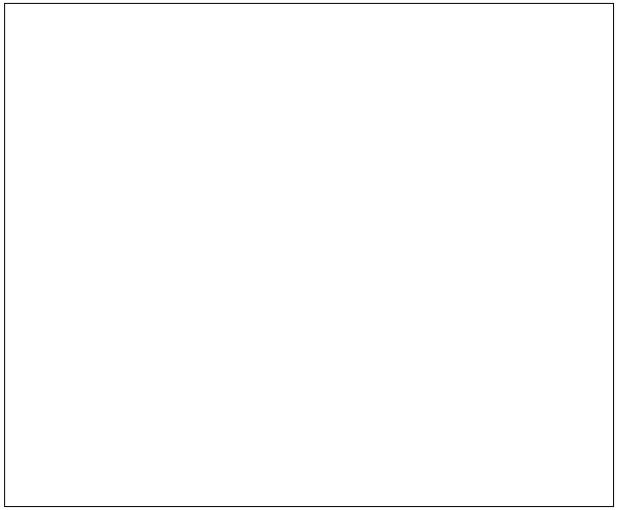
- Annotations to eliminate conflicts

4. Safe Integration with C



4. Safe Integration with C

- Abortion of trails dealing with resources is unsafe

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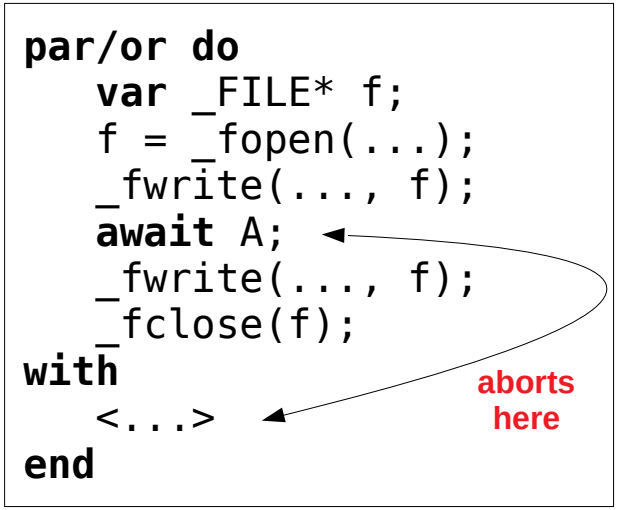
- Finalization mechanism



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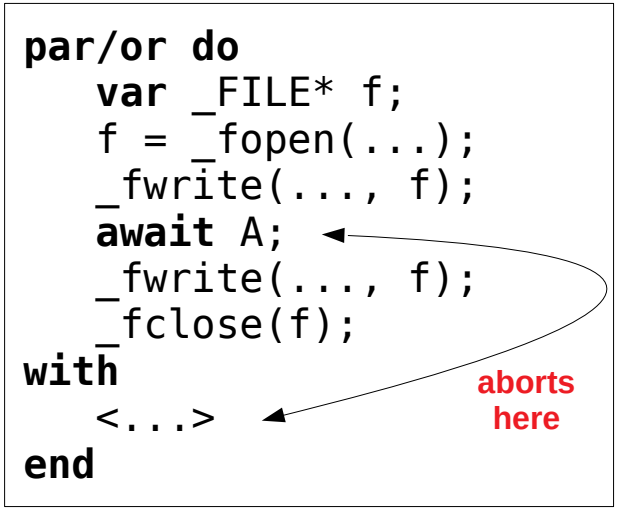

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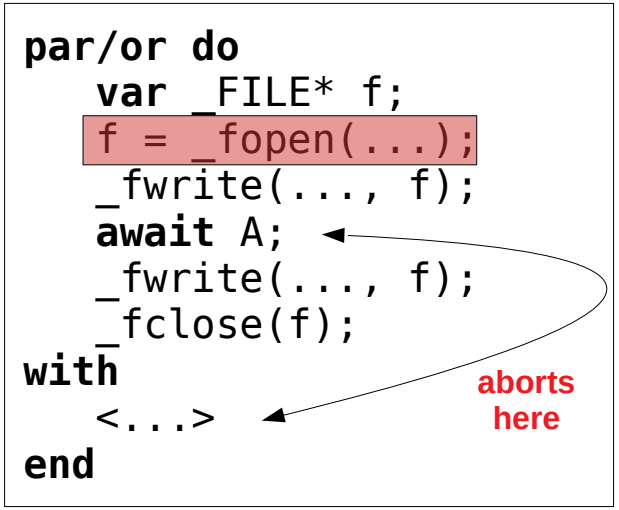

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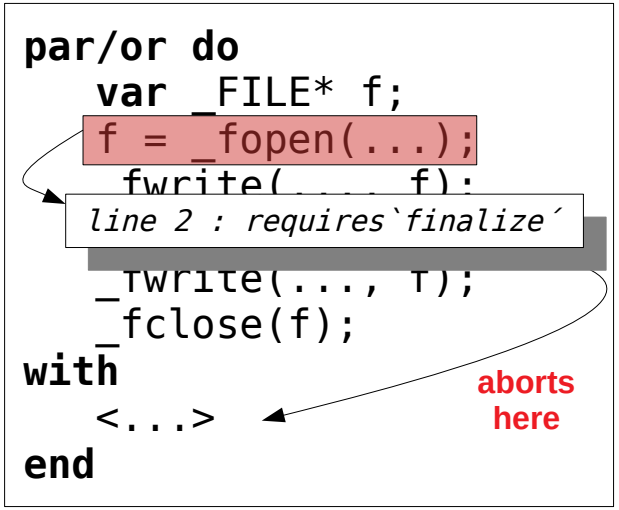

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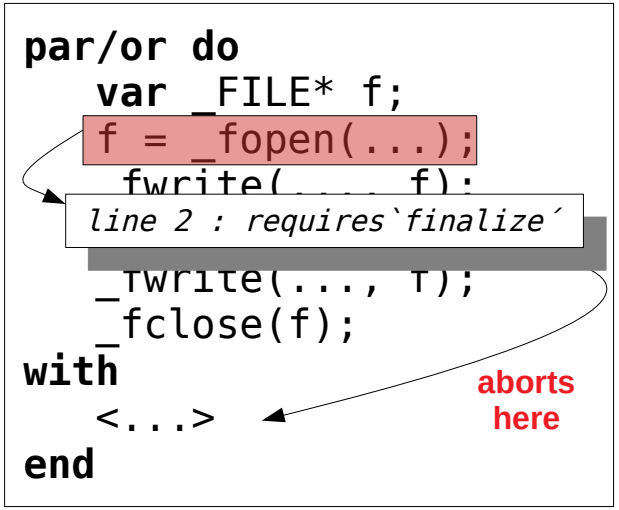


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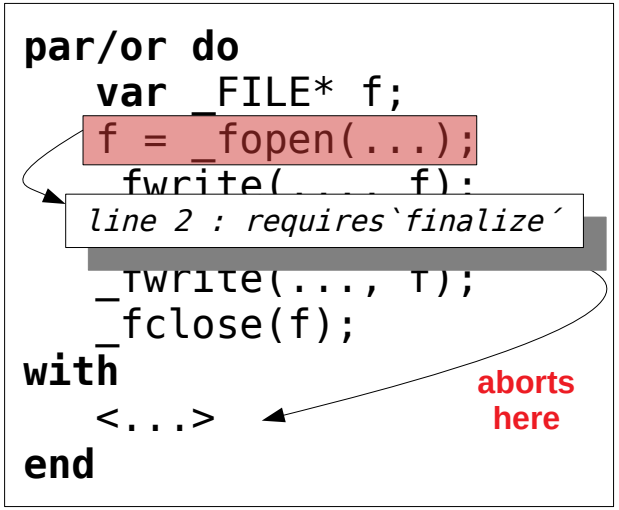


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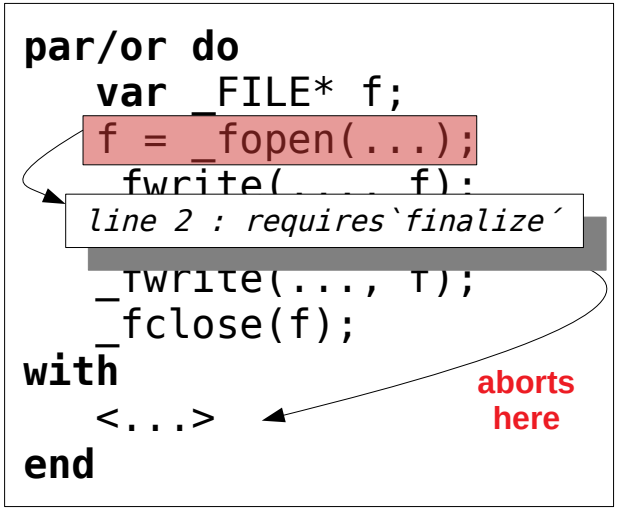


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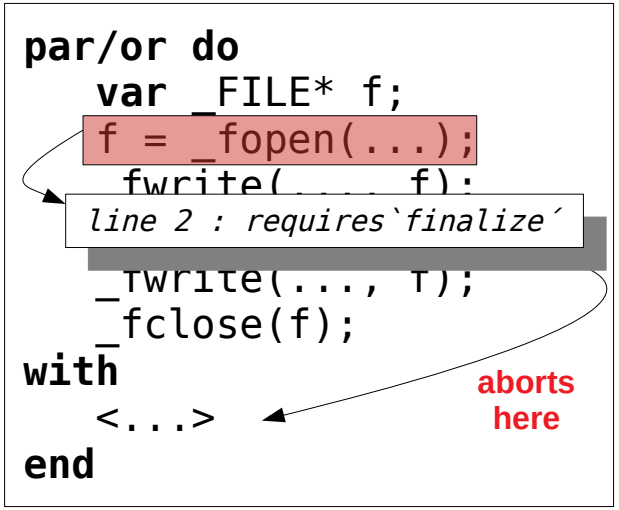


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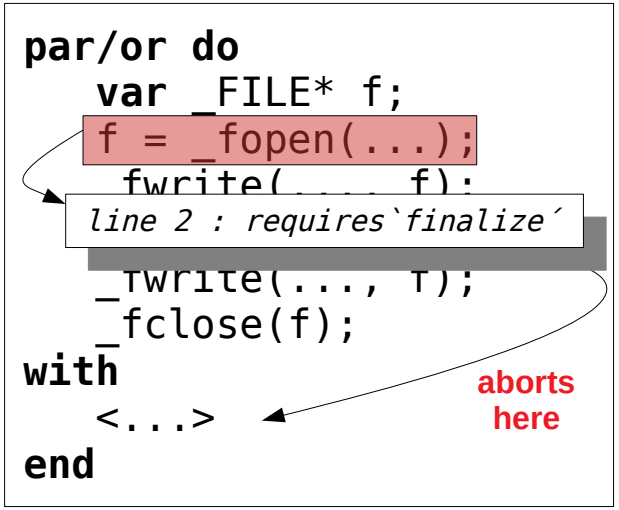


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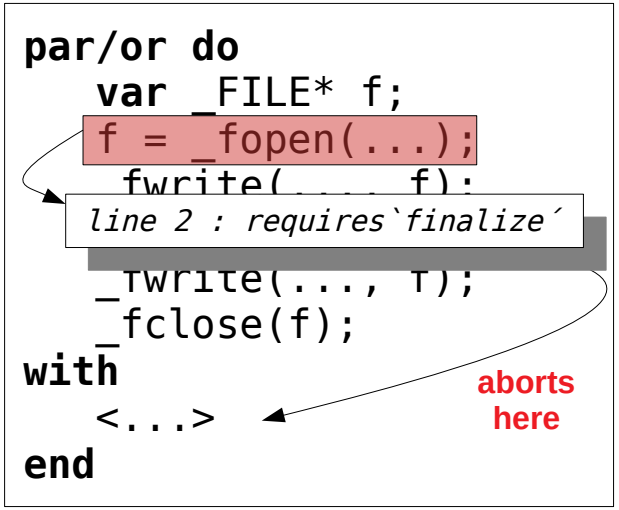


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```
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```

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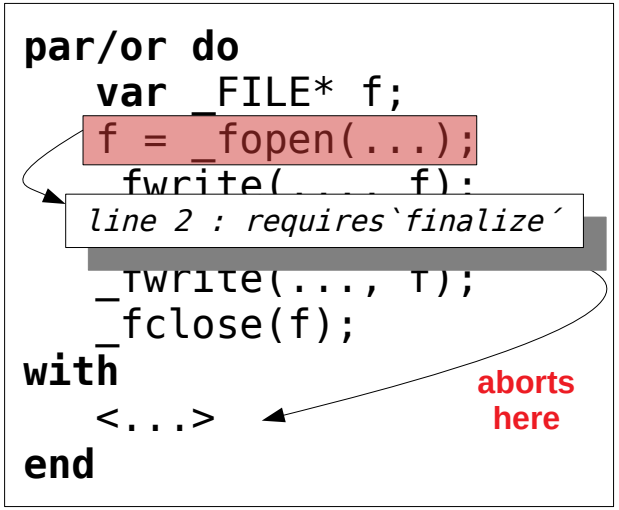


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   <...>
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```

```
par/or do
   var _buffer_t msg;
```

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par/or do
   var _FILE* f;
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   <...>
end
```

line 2 : requires`finalize´

aborts here

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par/or do
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      f = _fopen(...);
   with
      _fclose(f);
   end
   _fwrite(..., f);
   await A;
   _fwrite(..., f);
with
   <...>
end
```

```
par/or do
   var _buffer_t msg;
   <...> // prepare msg
```

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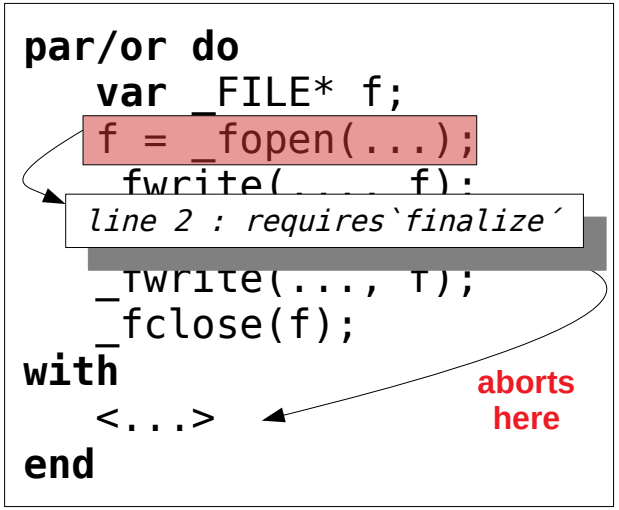


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   with
      _fclose(f);
   end
   _fwrite(..., f);
   await A;
   _fwrite(..., f);
with
   <...>
end
```

```
par/or do
   var _buffer_t msg;
   <...> // prepare msg
   finalize
      _send_request(&msg);
   with
      _send_cancel(&msg);
   end
```

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par/or do
   var _buffer_t msg;
   <...> // prepare msg
   finalize
      _send_request(&msg);
   with
      _send_cancel(&msg);
   end
   await SEND_ACK;
with
   <...>
end
```

5. First-Class Timers

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```
var int v;
await 10ms;
v = 1;
await 1ms;
v = 2;
```

5. First-Class Timers

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  1. Dedicated syntax
  2. Delta compensation (system vs program mismatch)

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```

15ms from system clock

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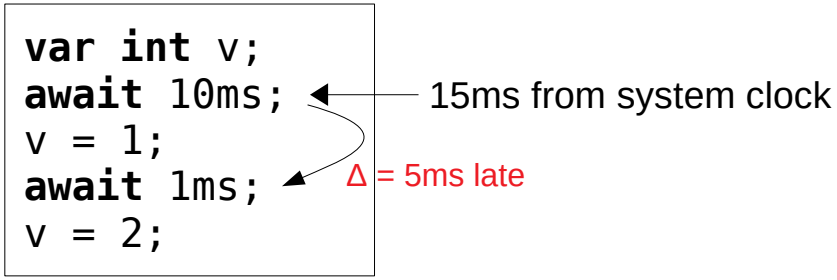

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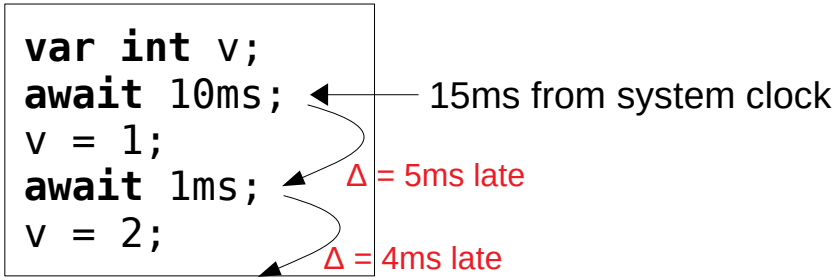

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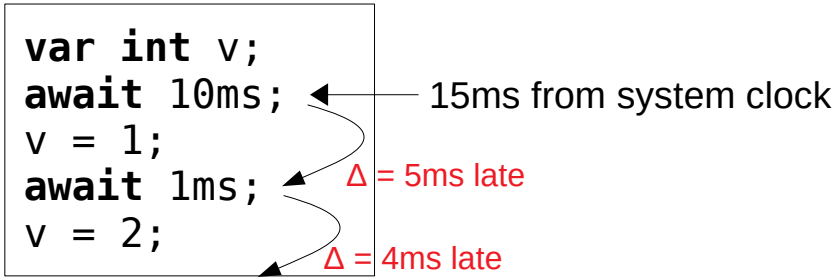


```
var int v;
par/or do
   await 10ms;
   await 1ms;
   v = 1;
with
   await 12ms;
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end
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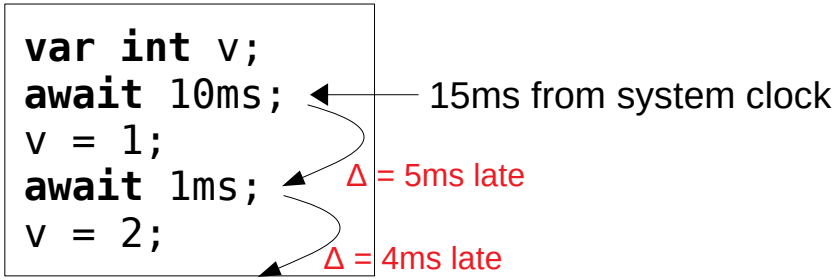


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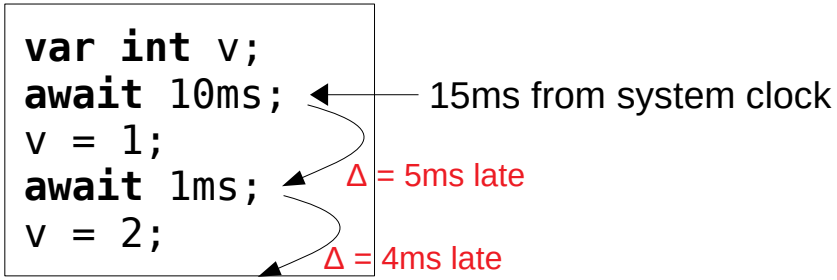


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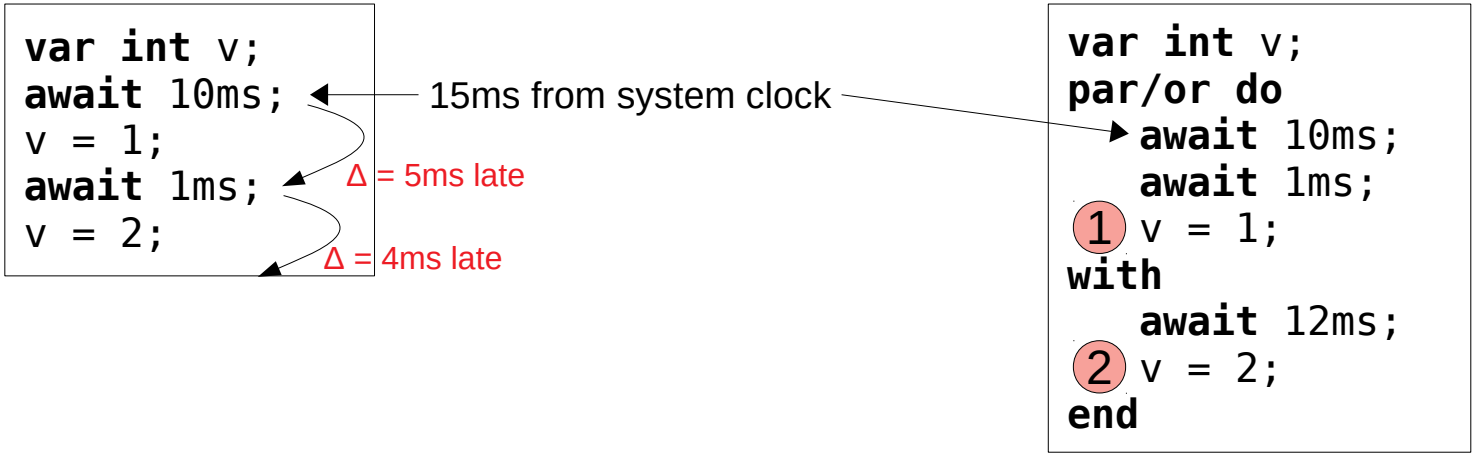

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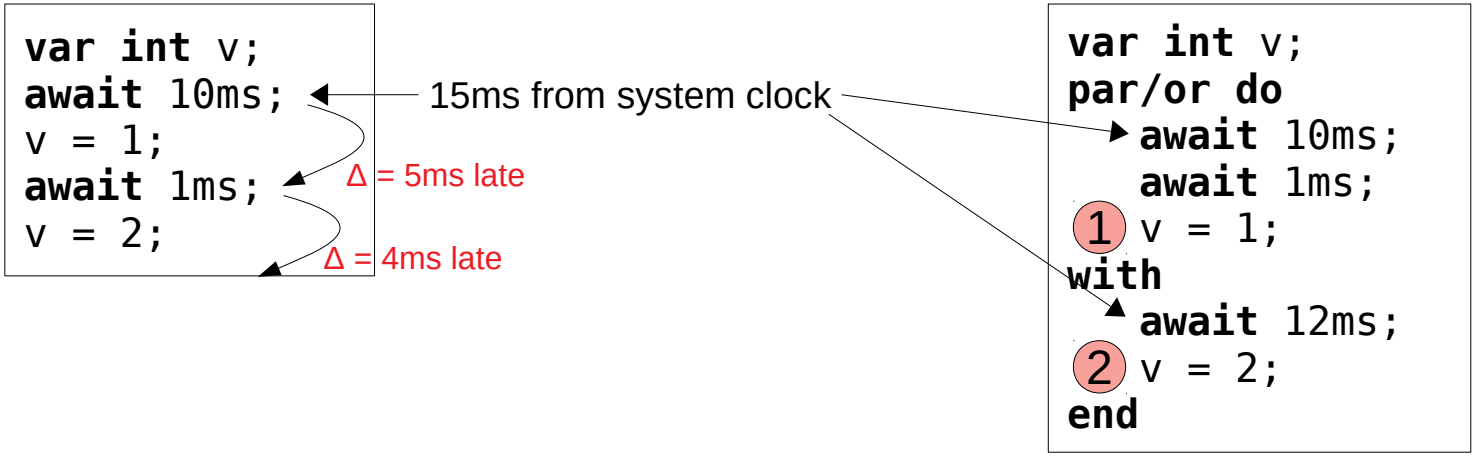

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  - **remote reprogramming**

Céu Peculiarities

1. External events
   - time is a queue of unique external events
2. Internal events
   - intra reactions, stack based
3. Concurrency: internal determinism + static checks
   - simple, concurrent assignments/system calls
4. Safe integration with C
   - finalization for local/external resources
5. First-class timers
   - dedicated syntax, automatic synchronization

An Overview of Céu

A synchronous language inspired by Esterel

Francisco Sant'Anna

francisco@ime.uerj.br

www.ceu-lang.org

1. External Events

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Esterel
(fixed tick)

Céu
(unique input)

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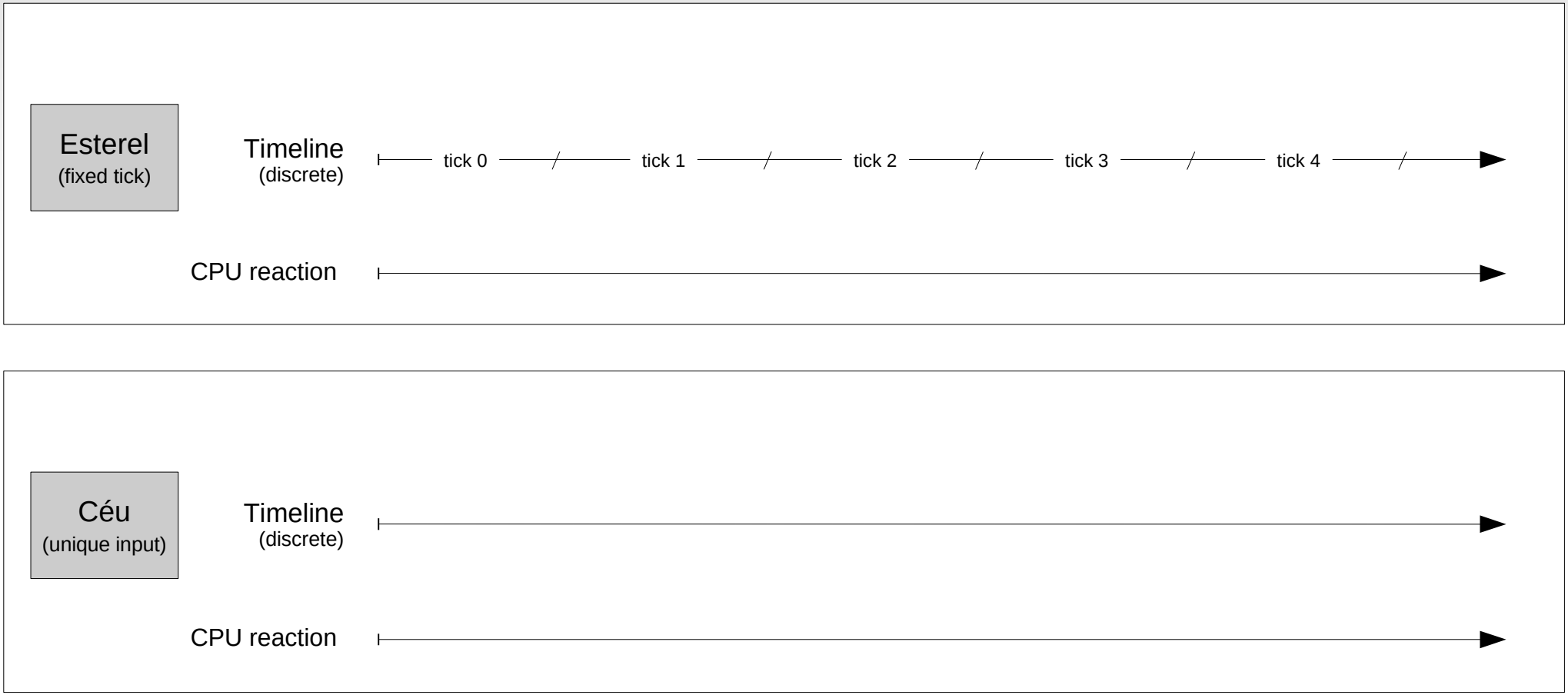

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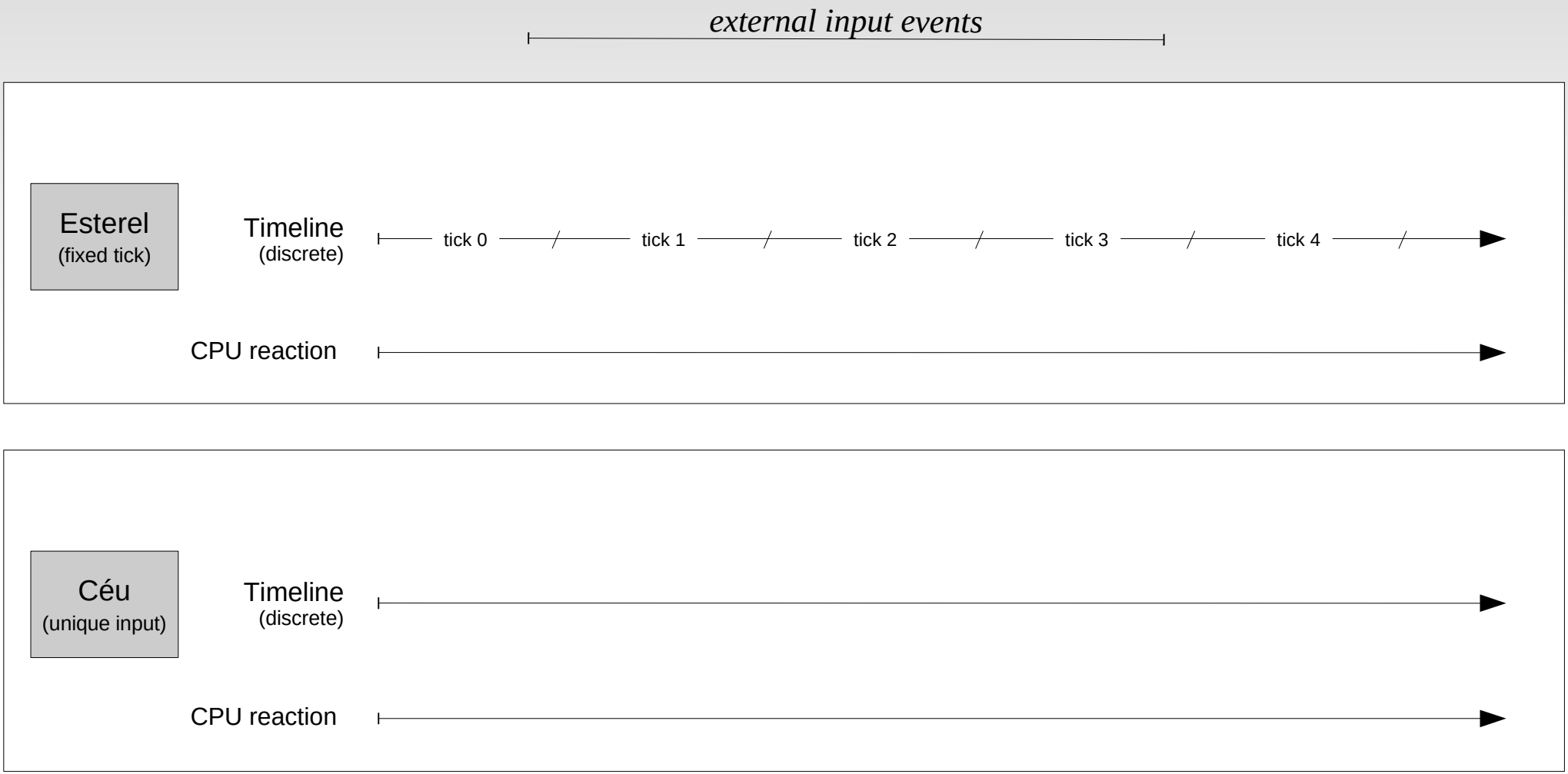

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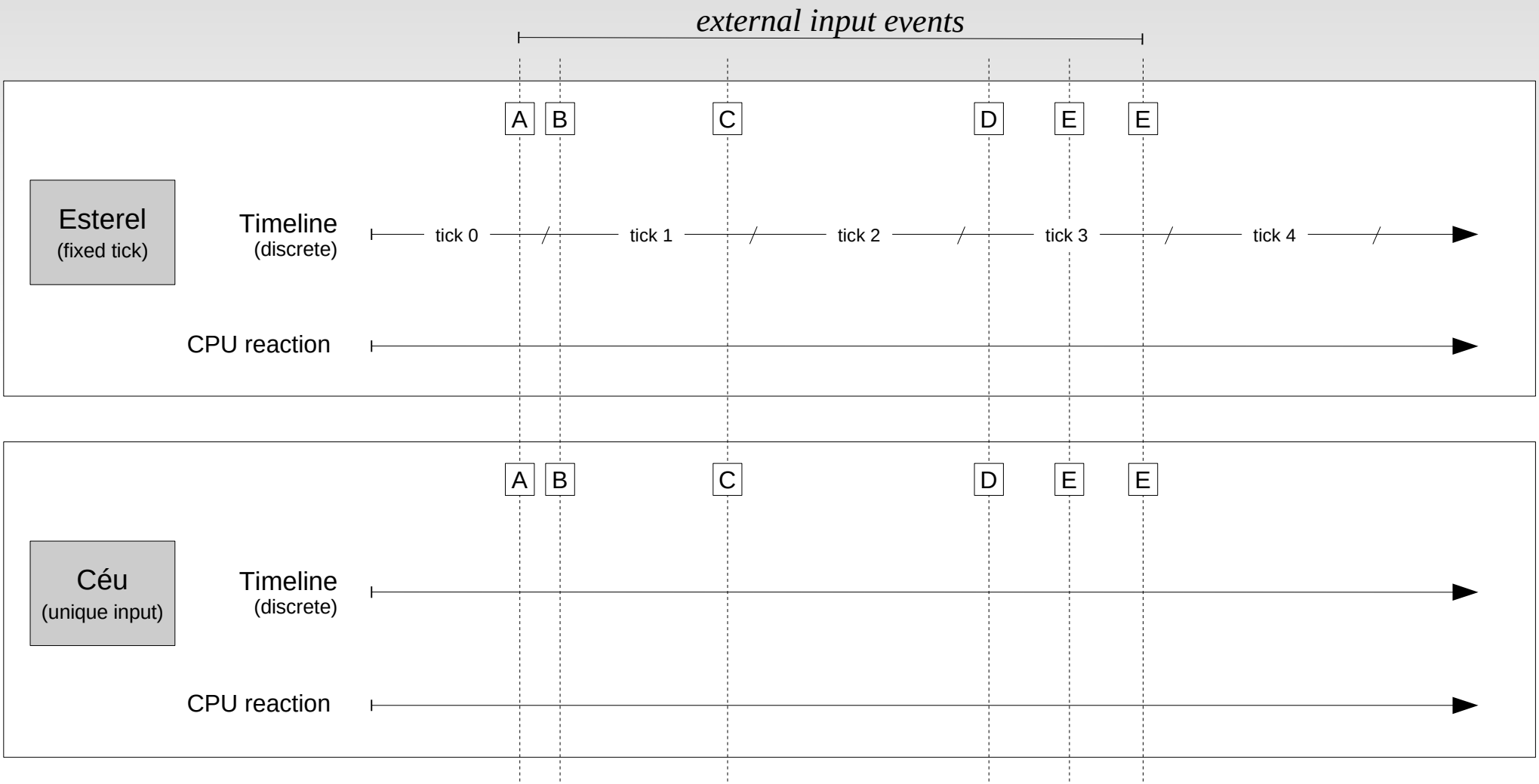

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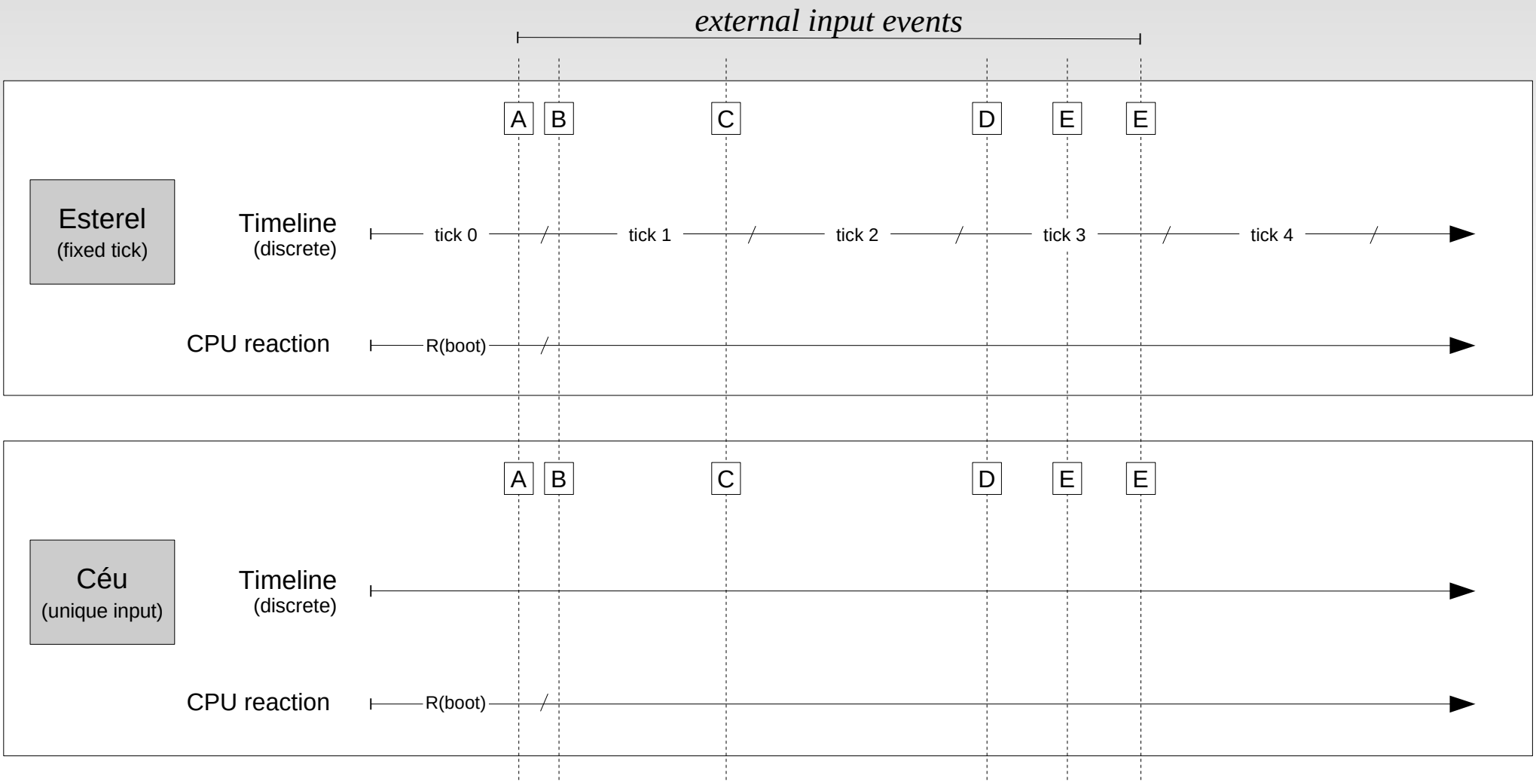
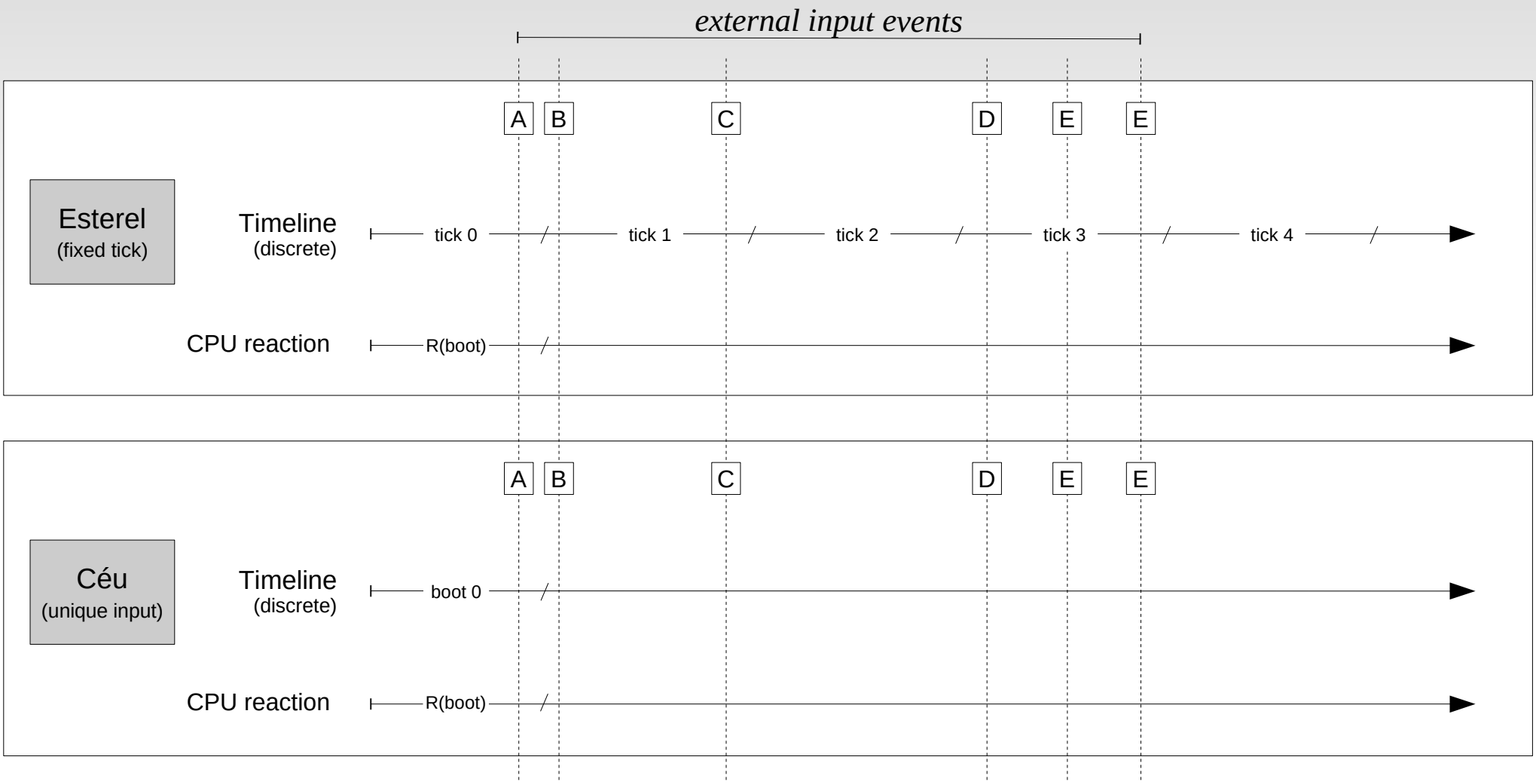


1. External Events



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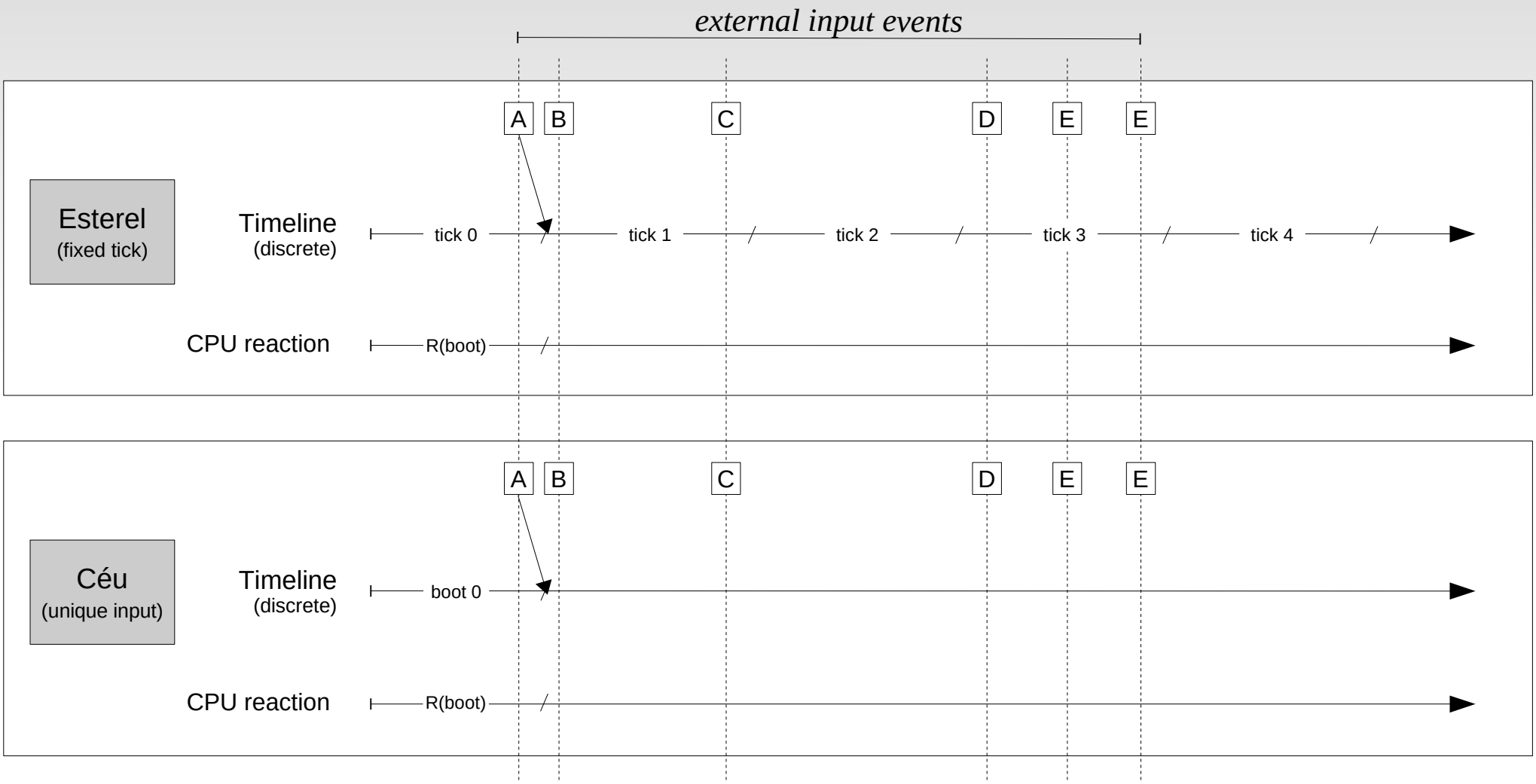

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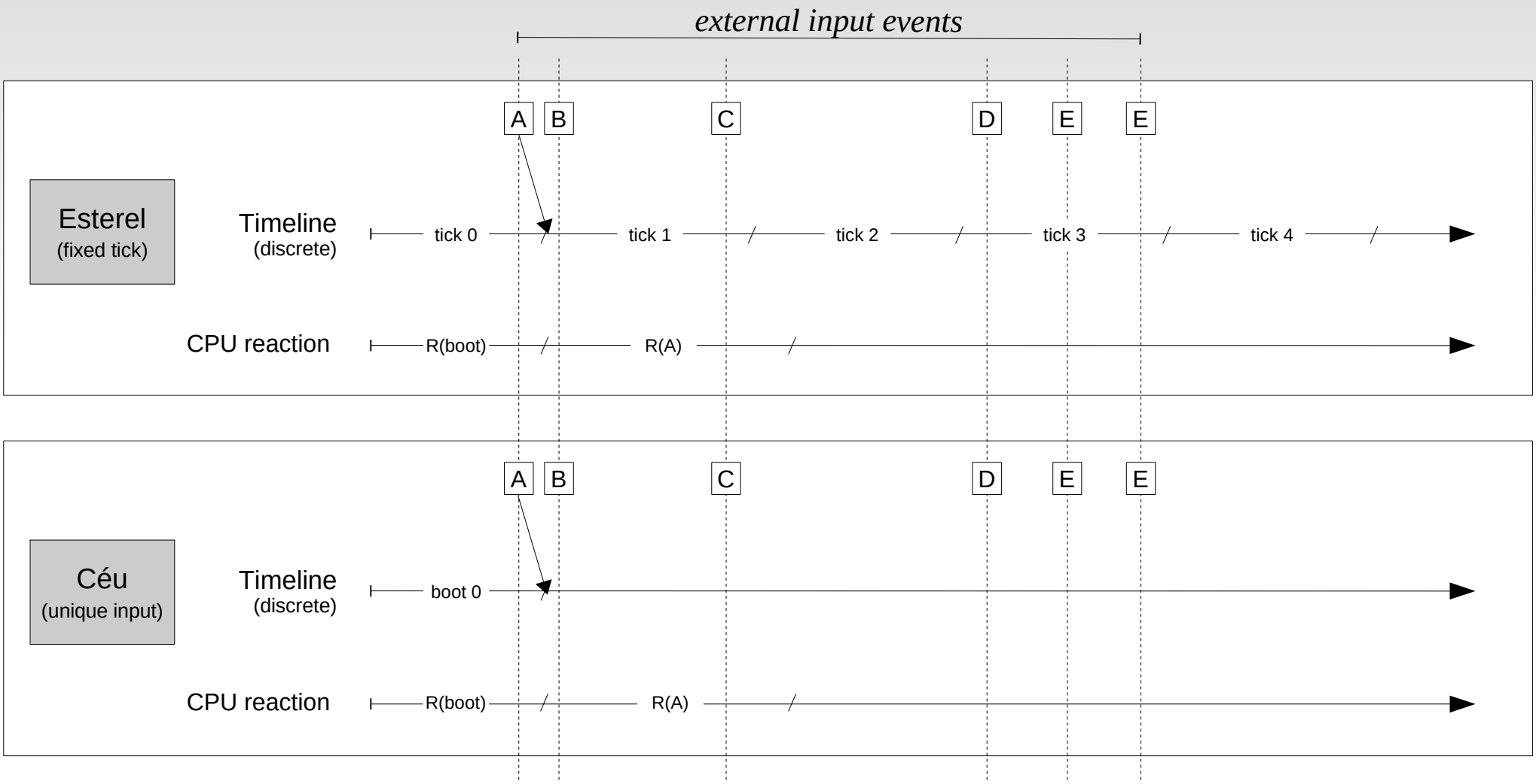

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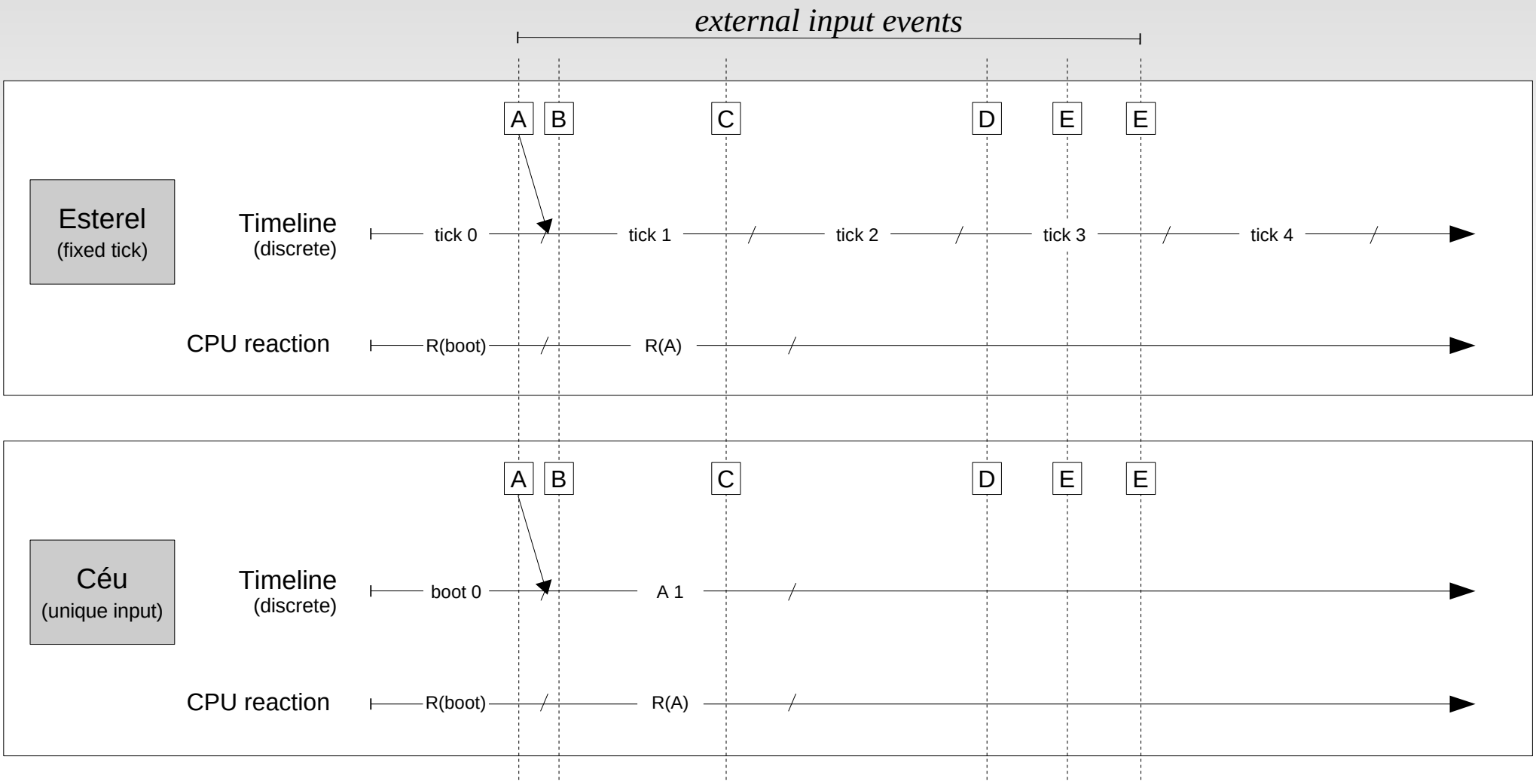

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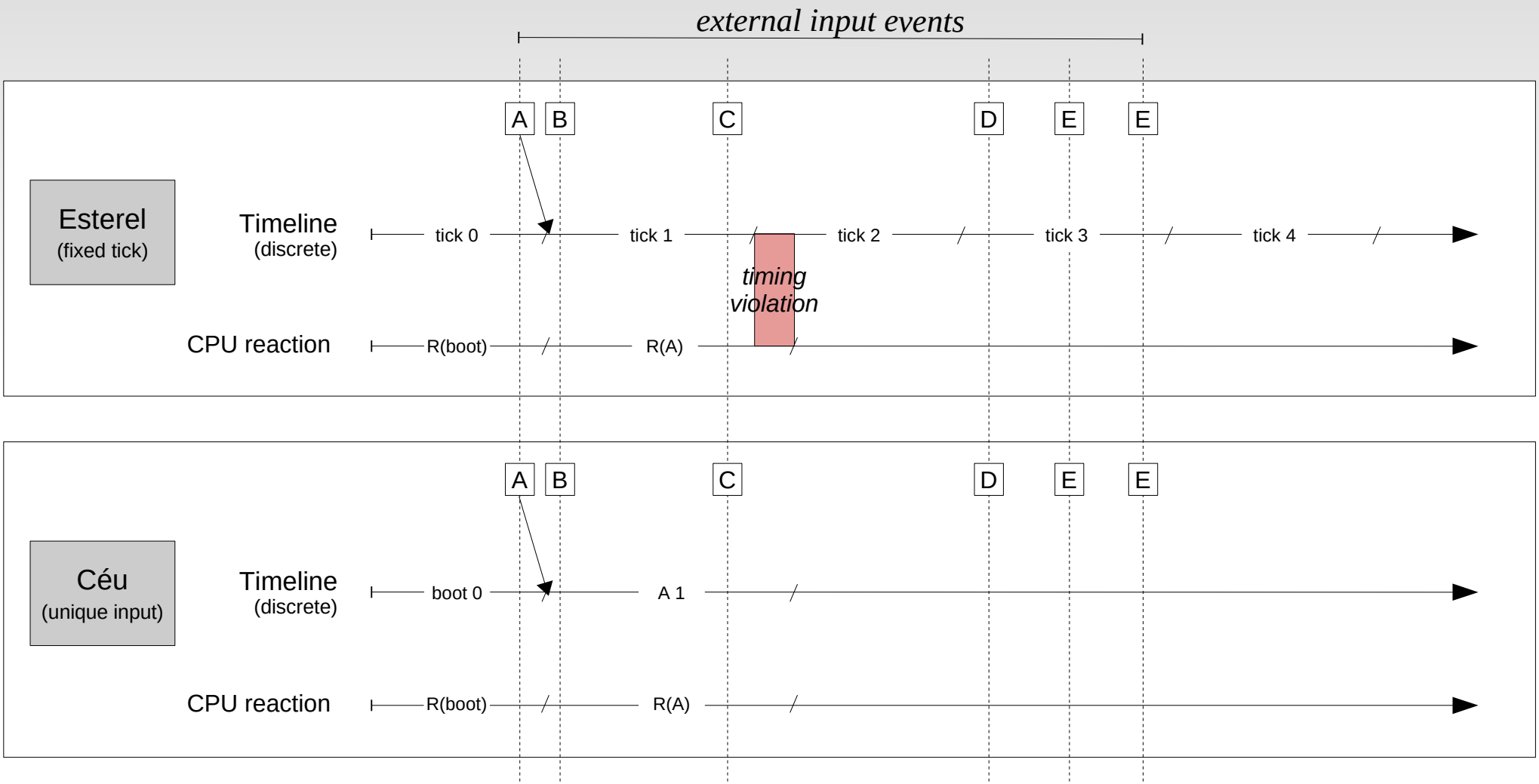

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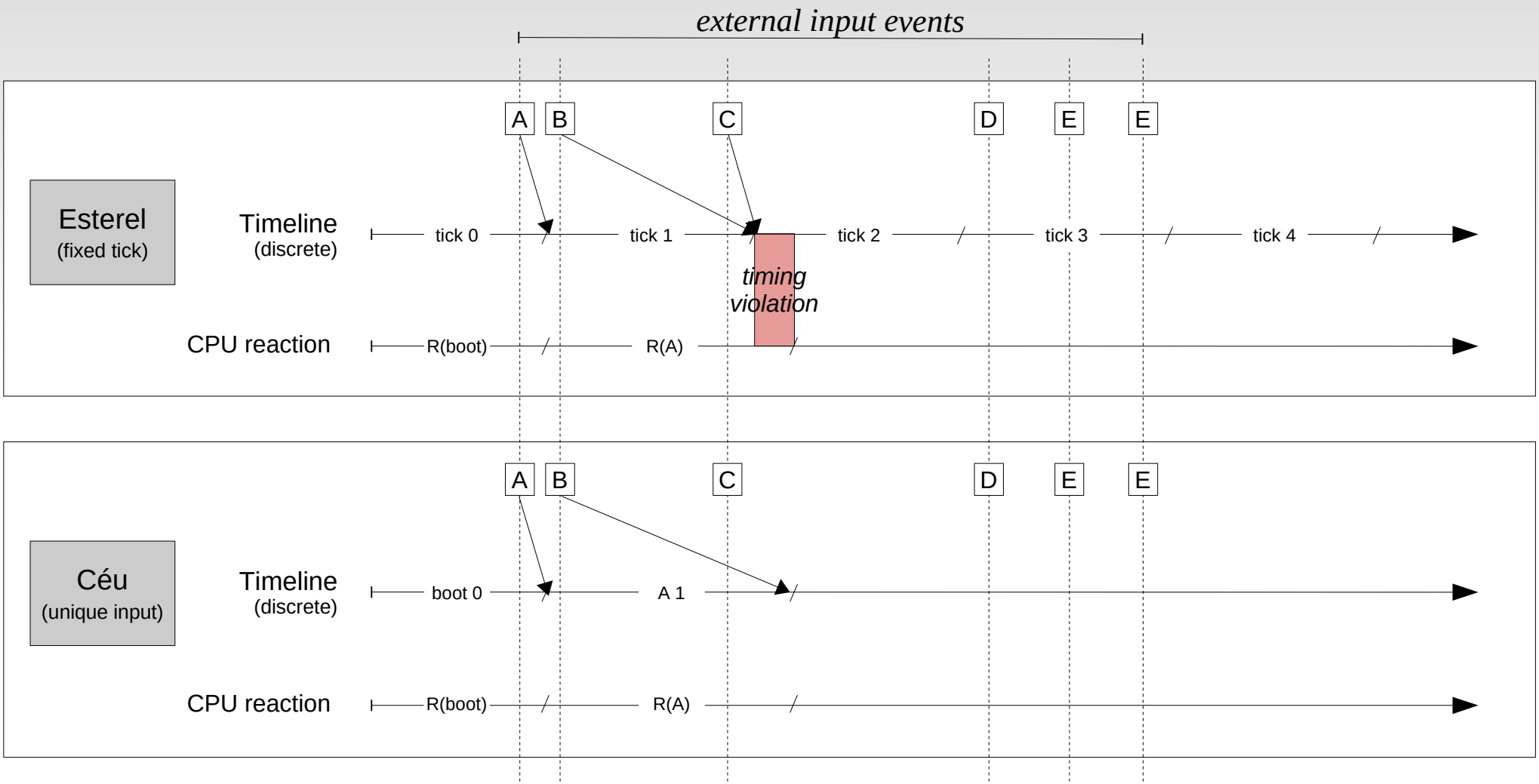

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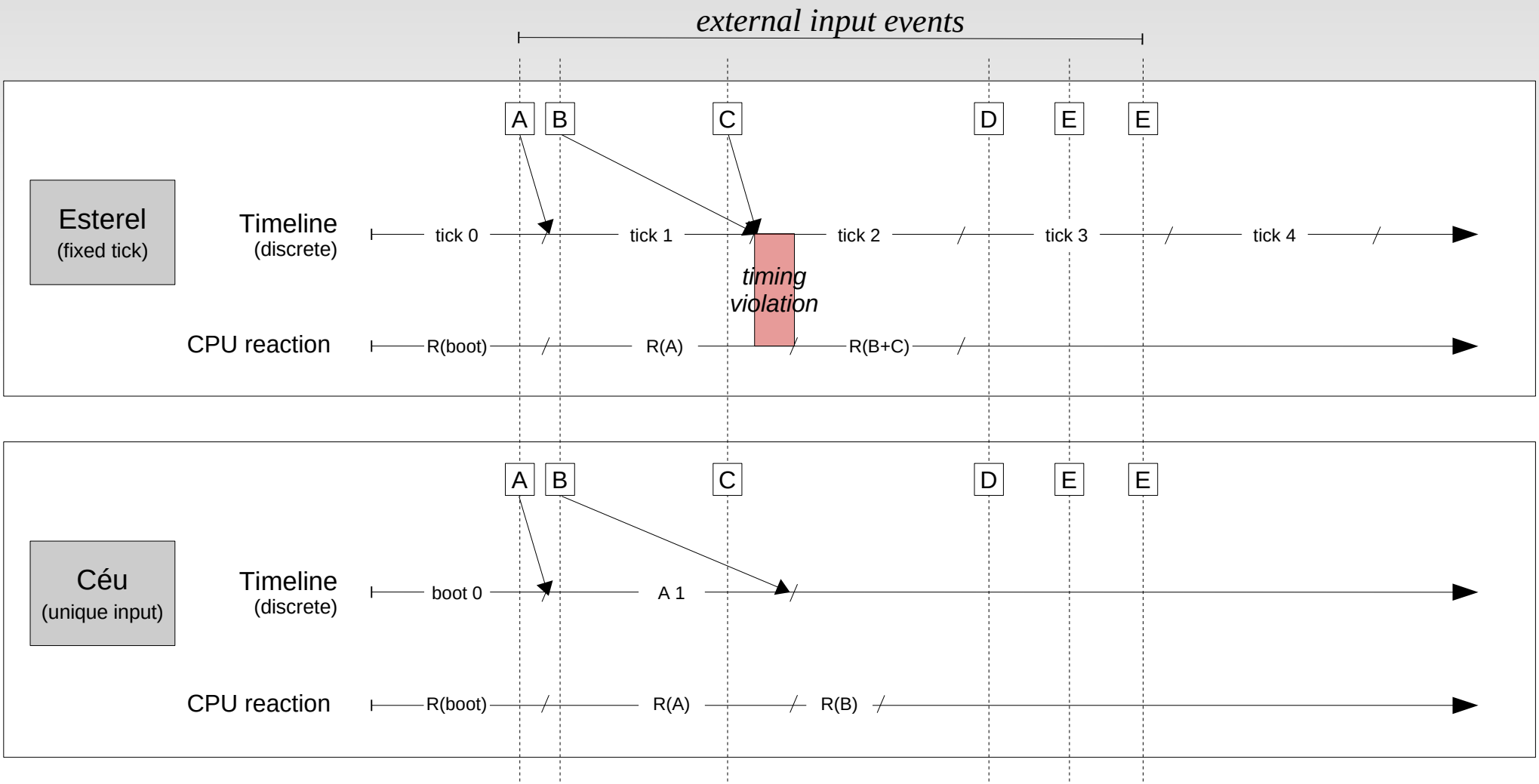

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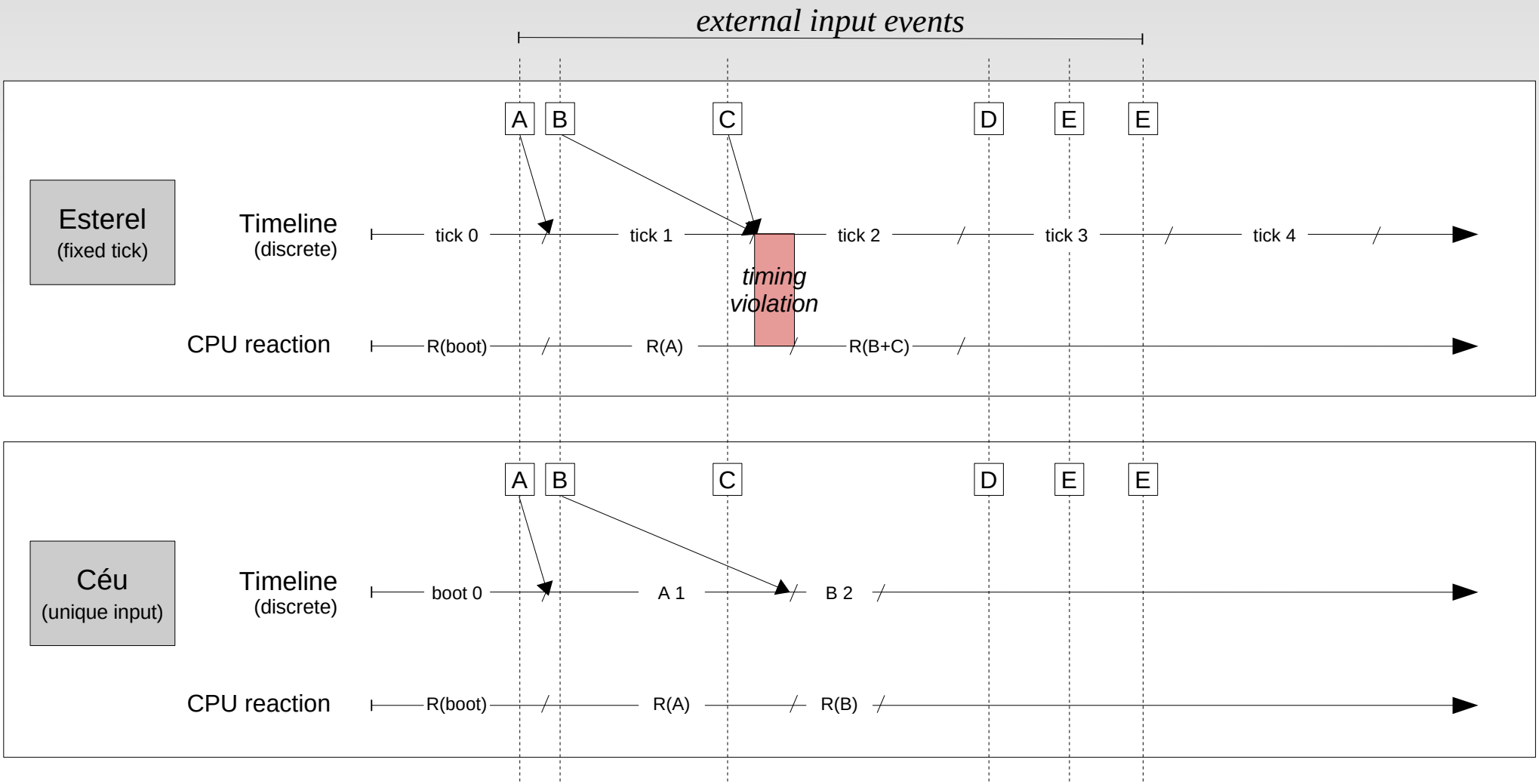

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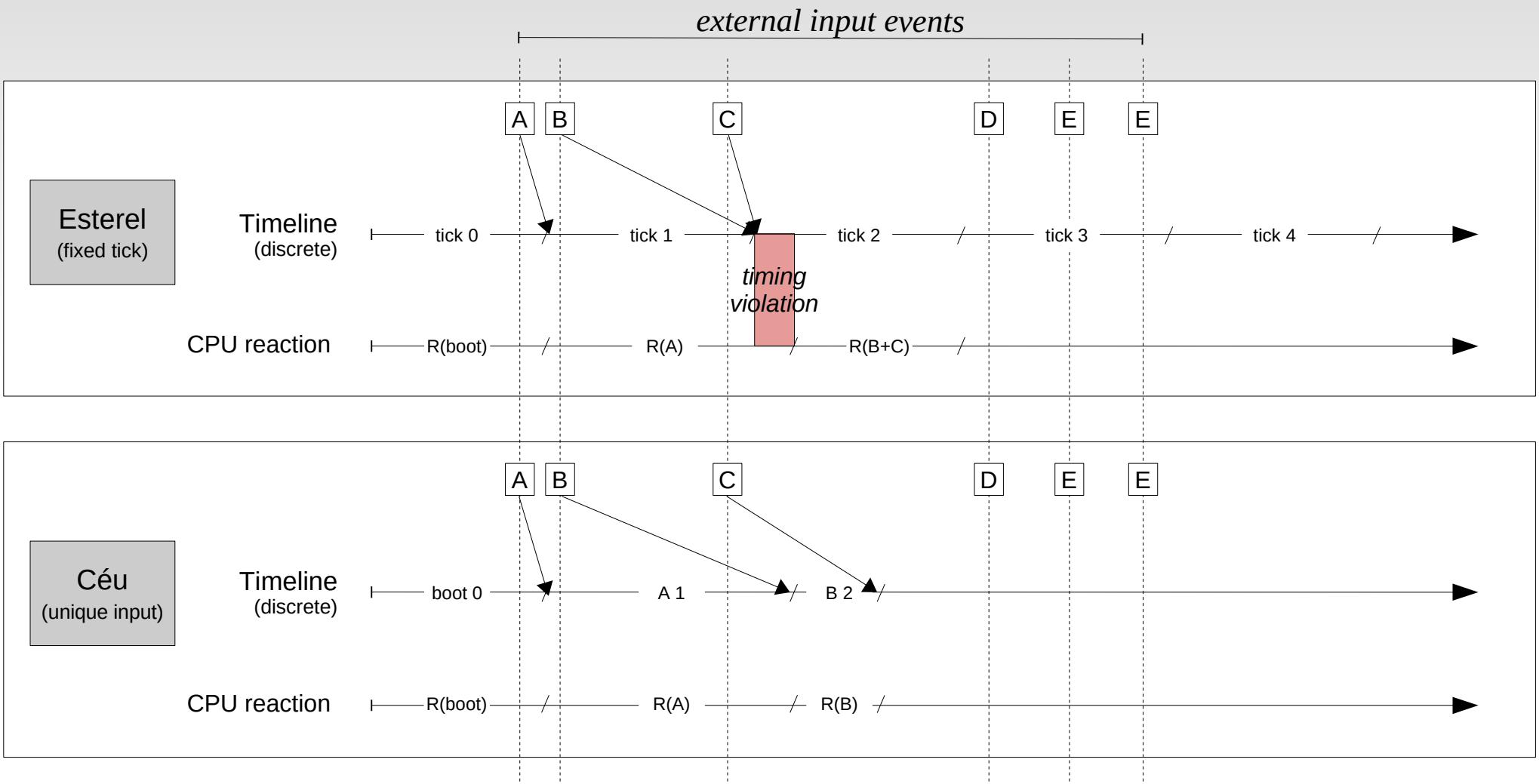

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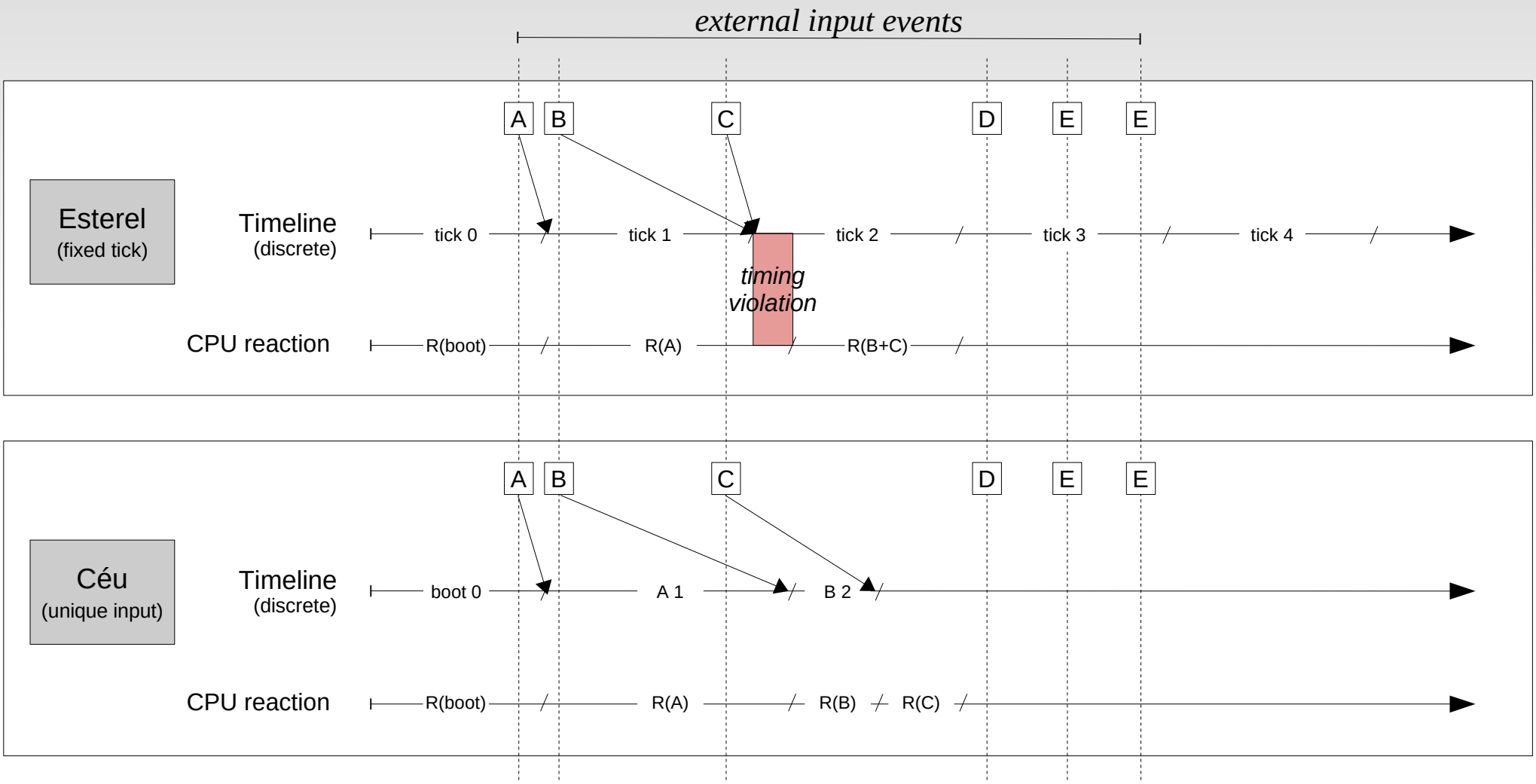

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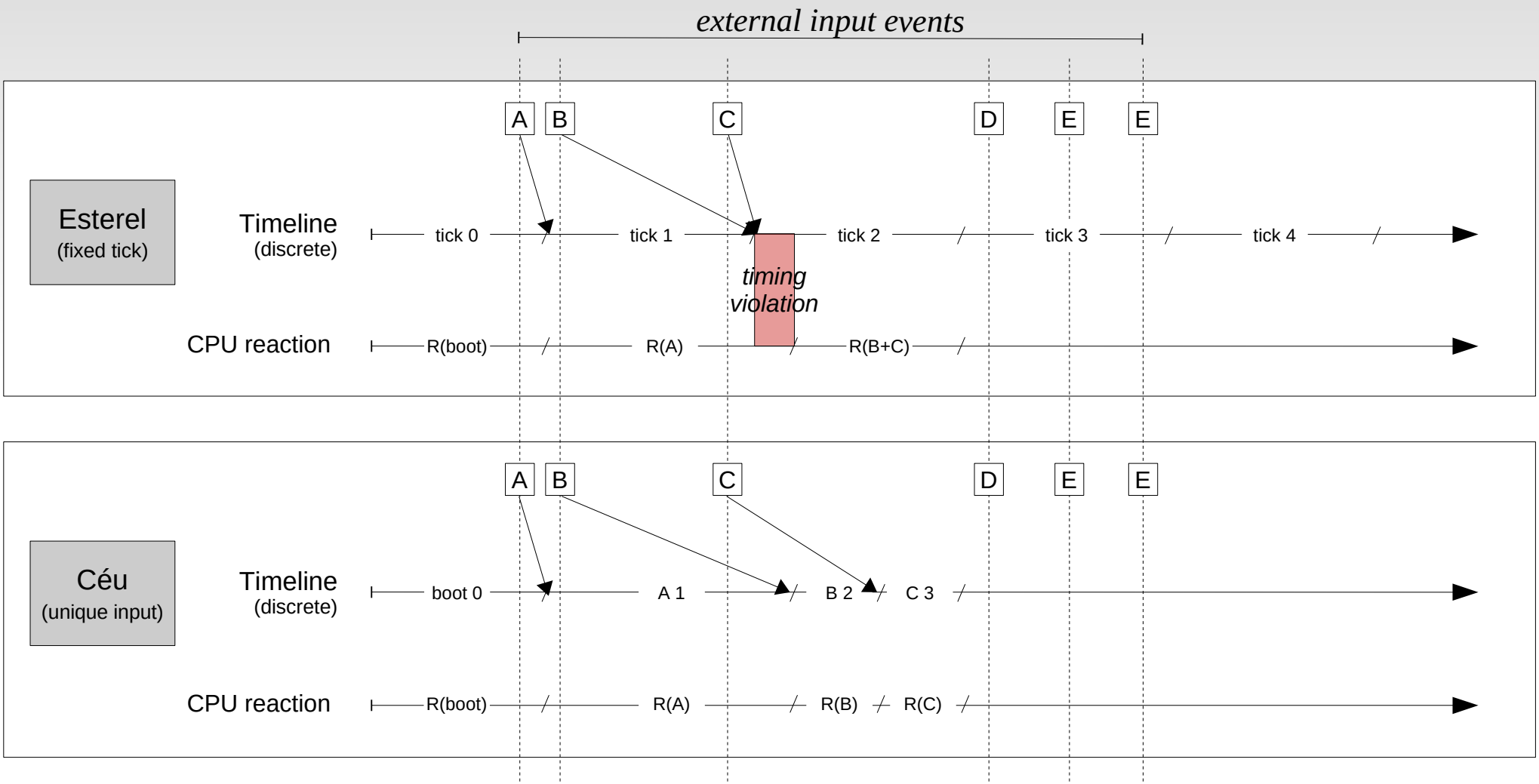

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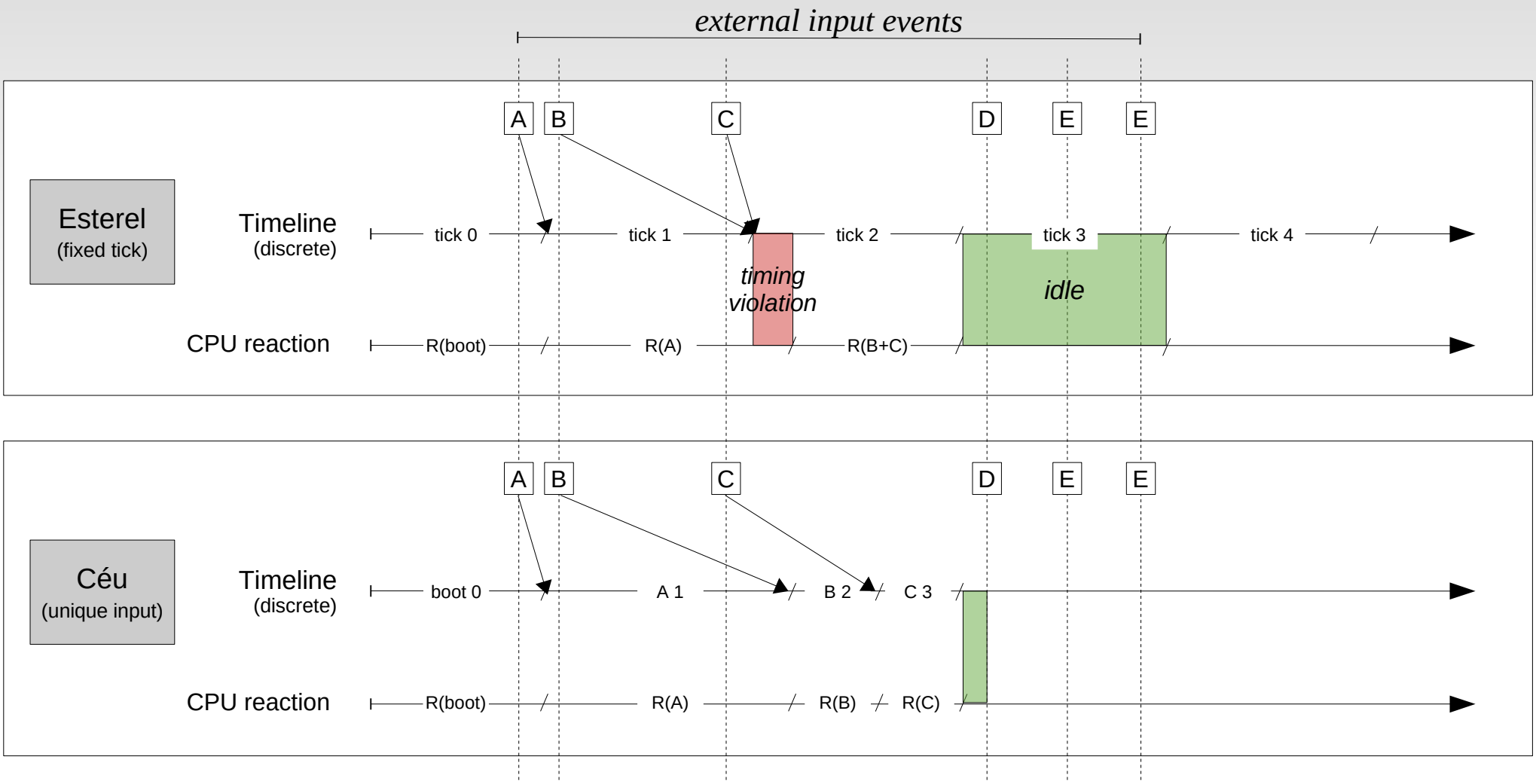

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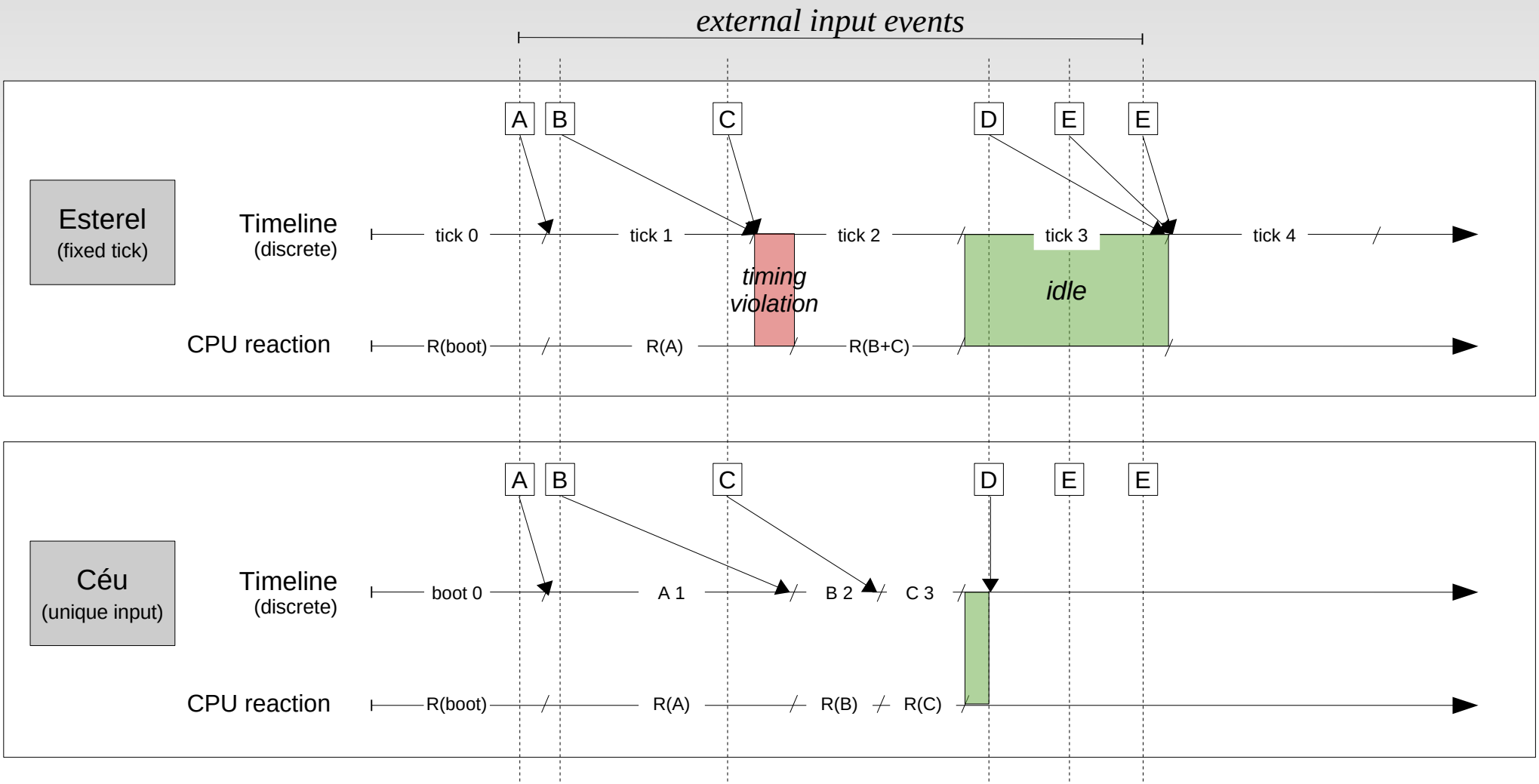

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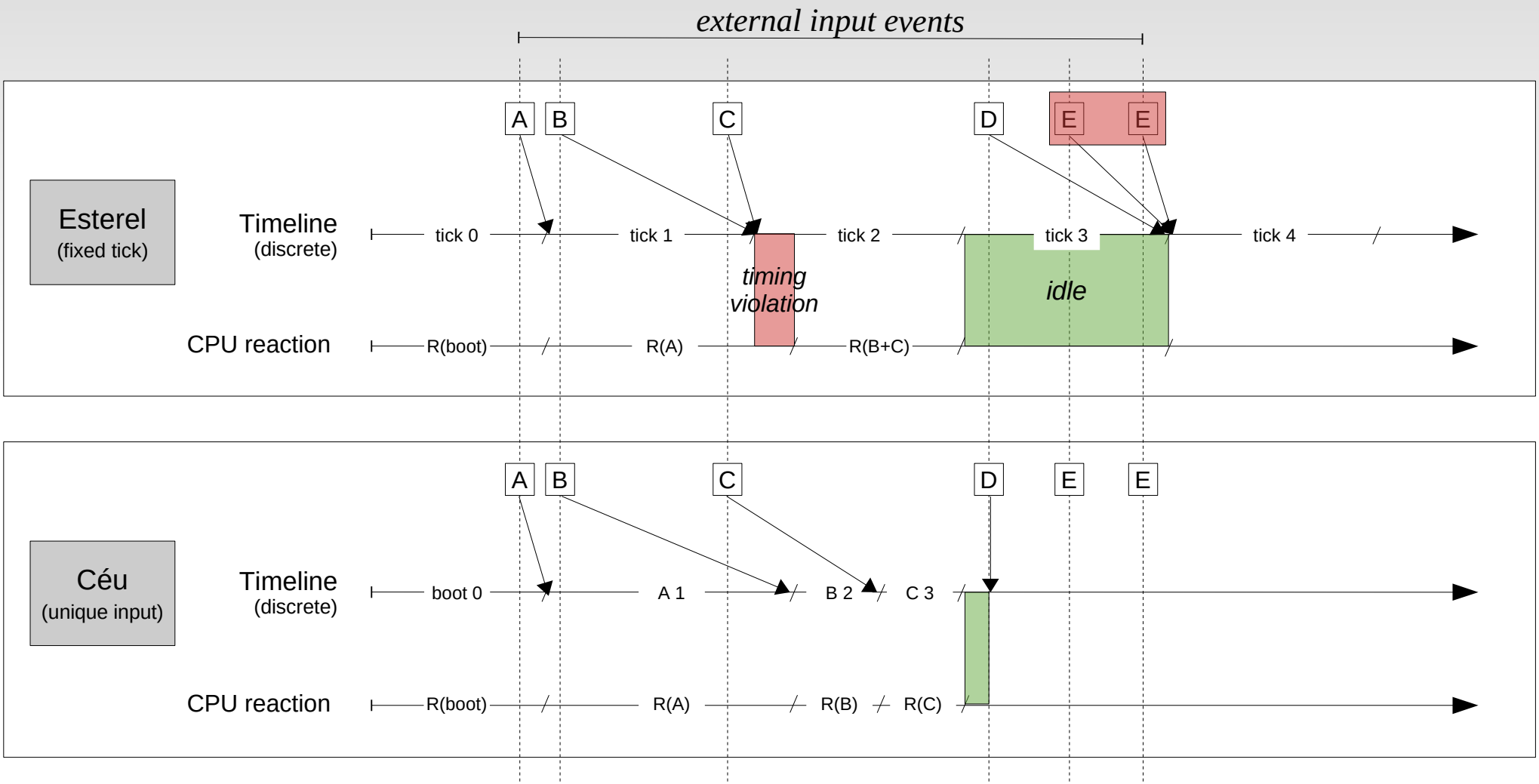

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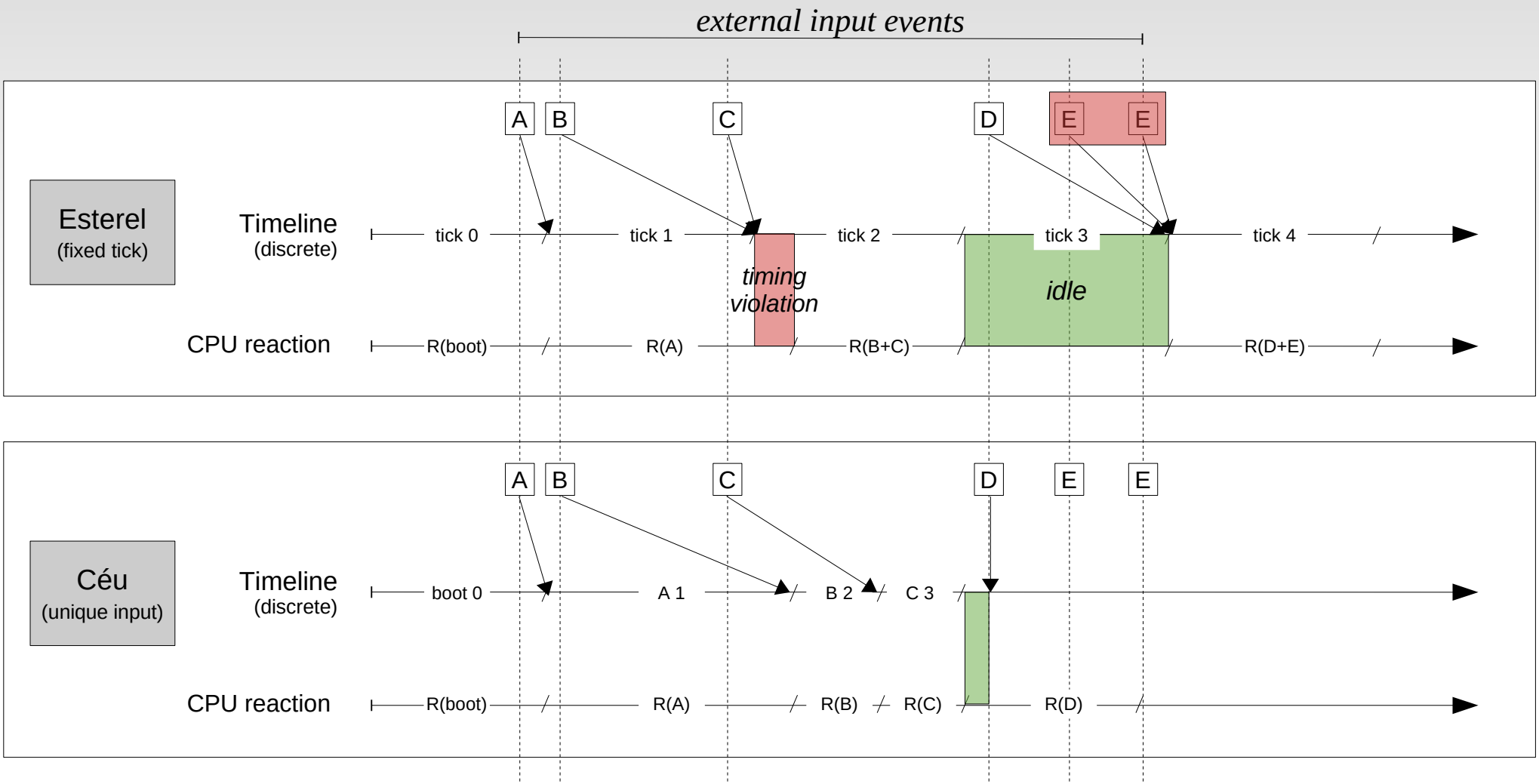

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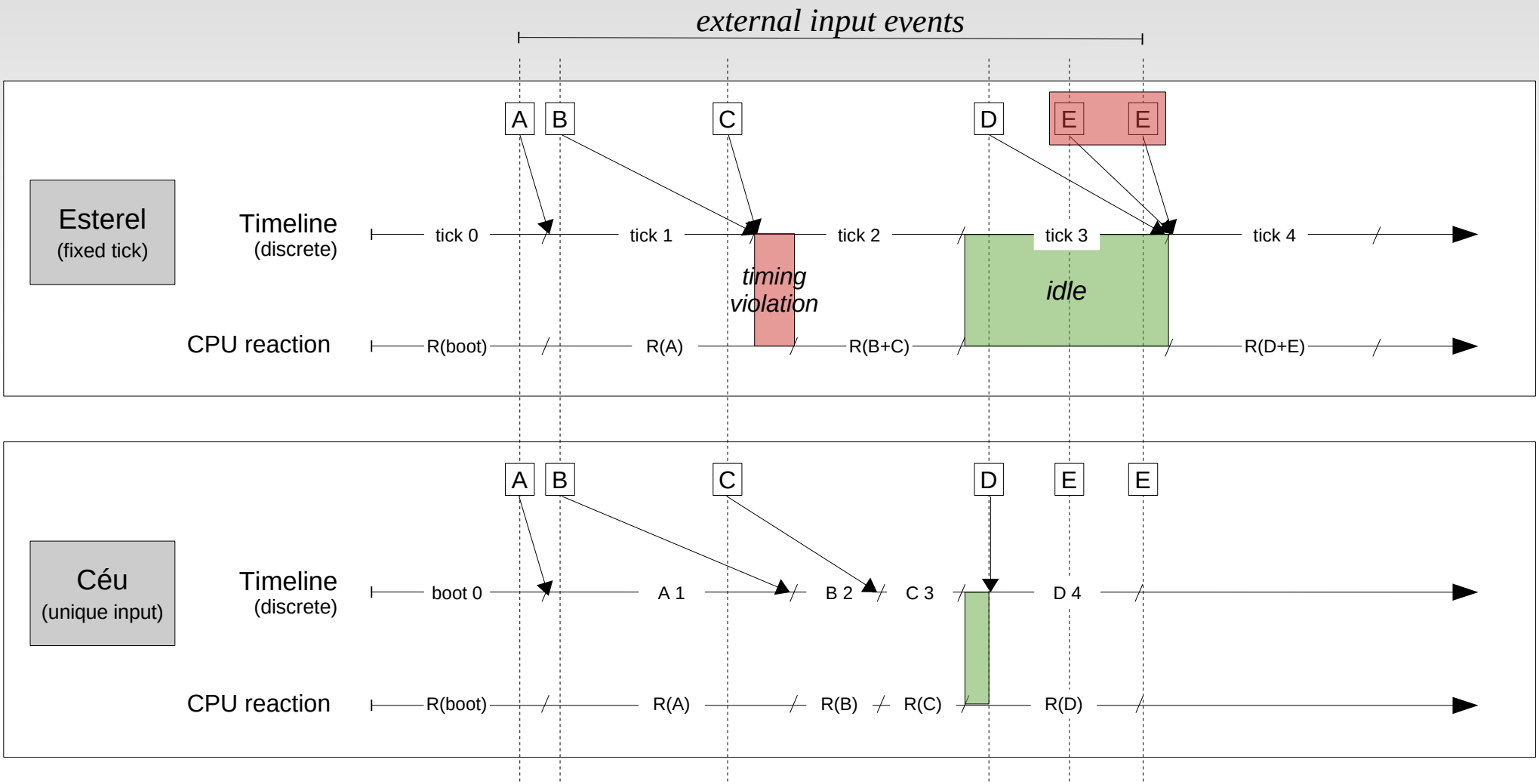

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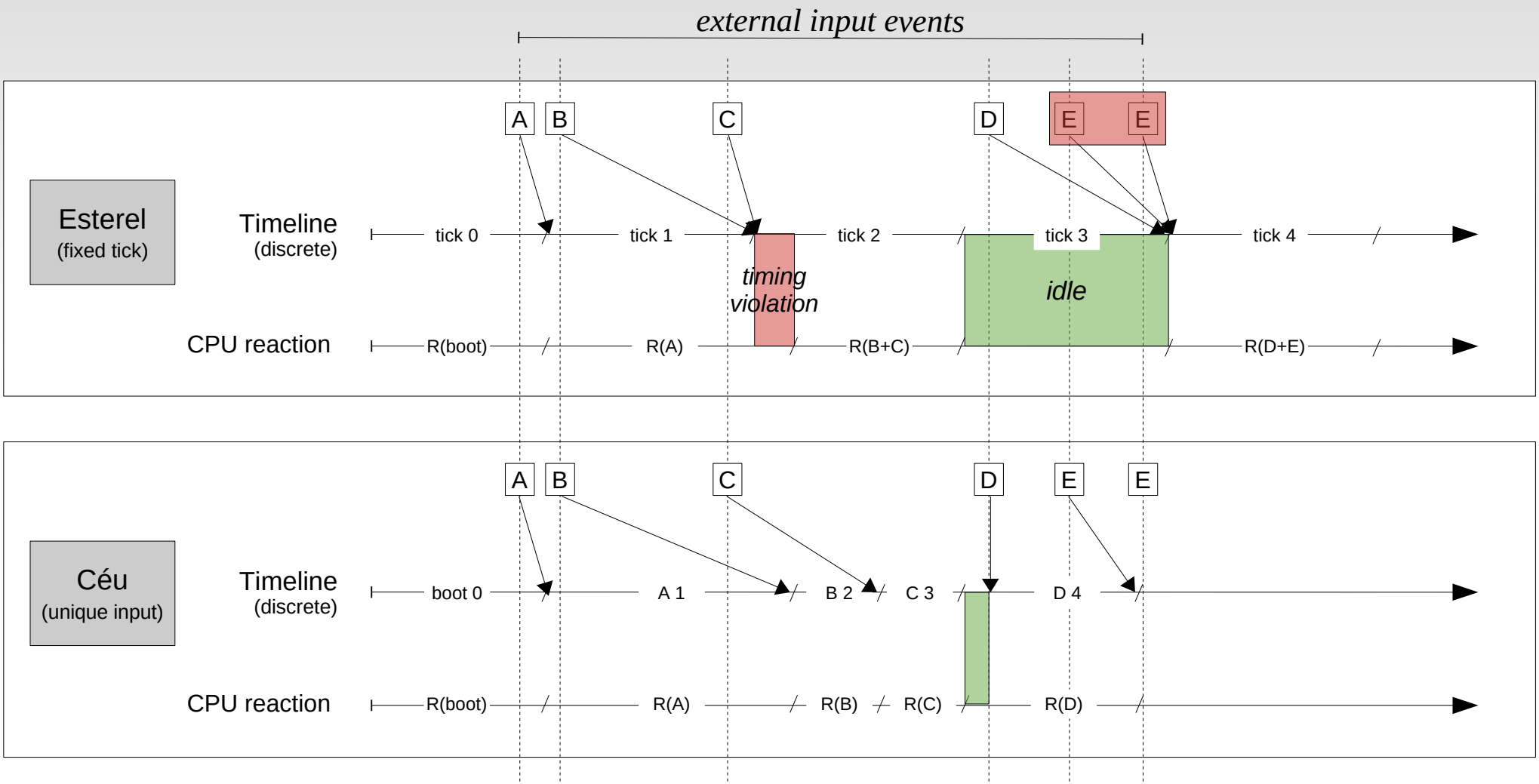

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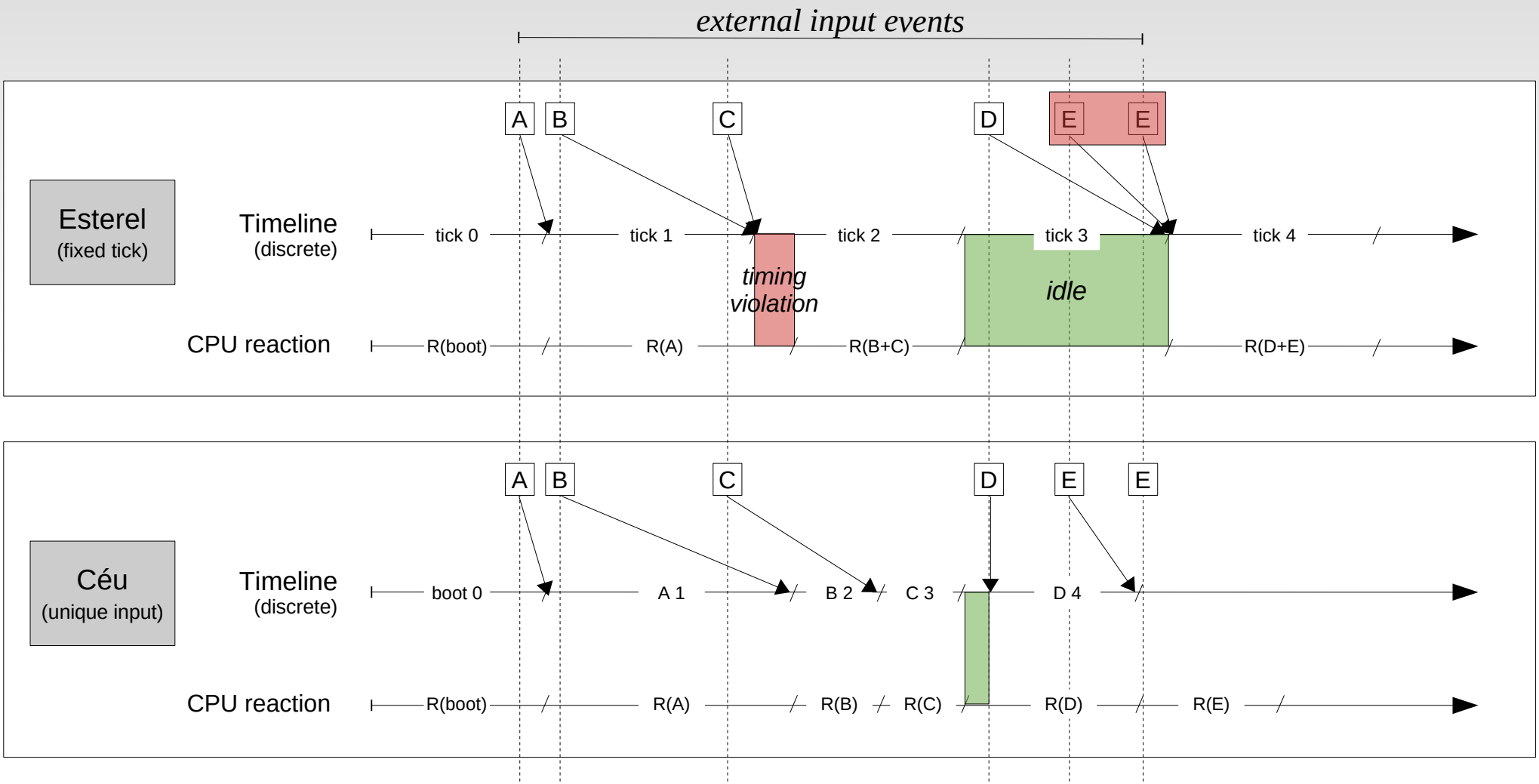

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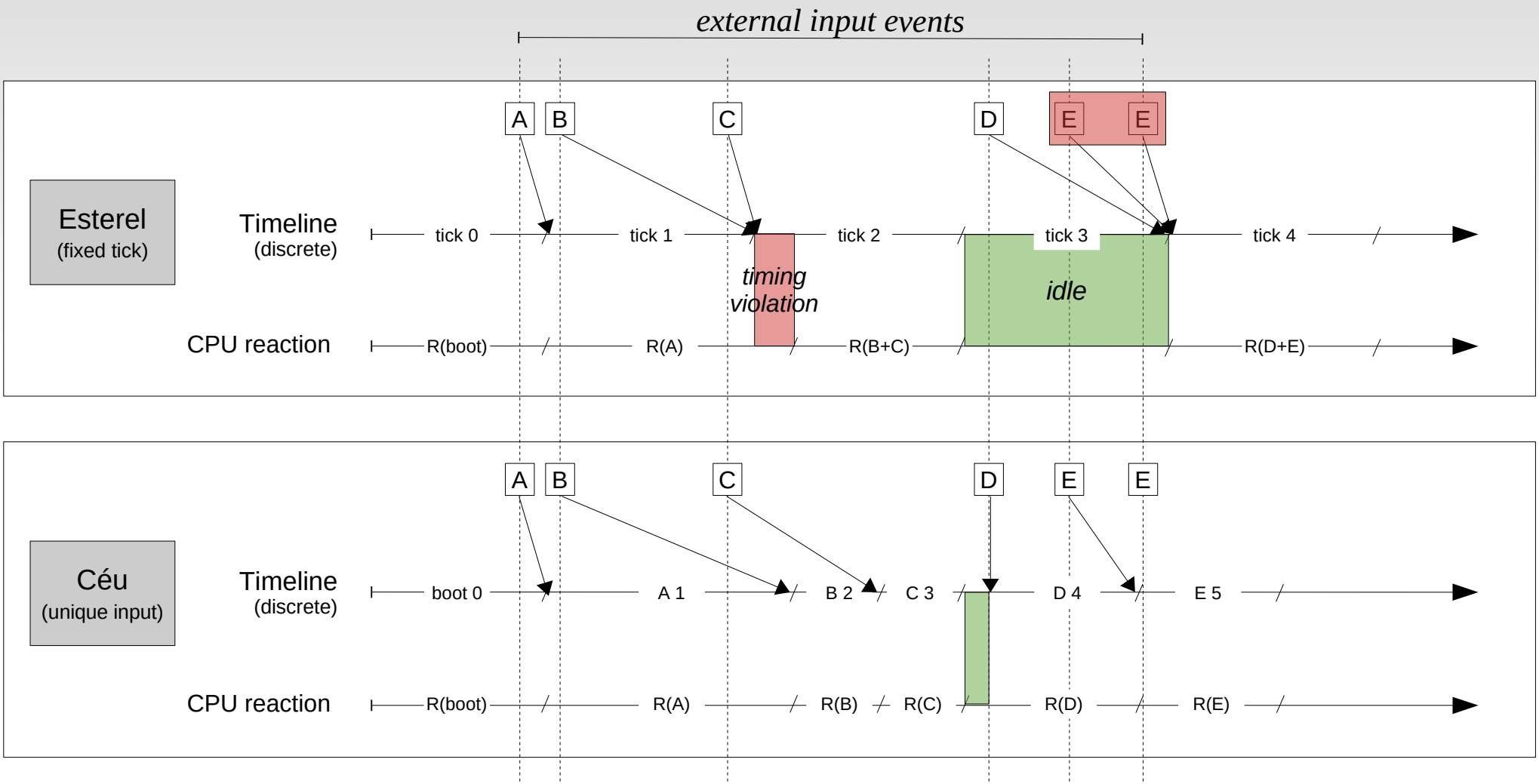

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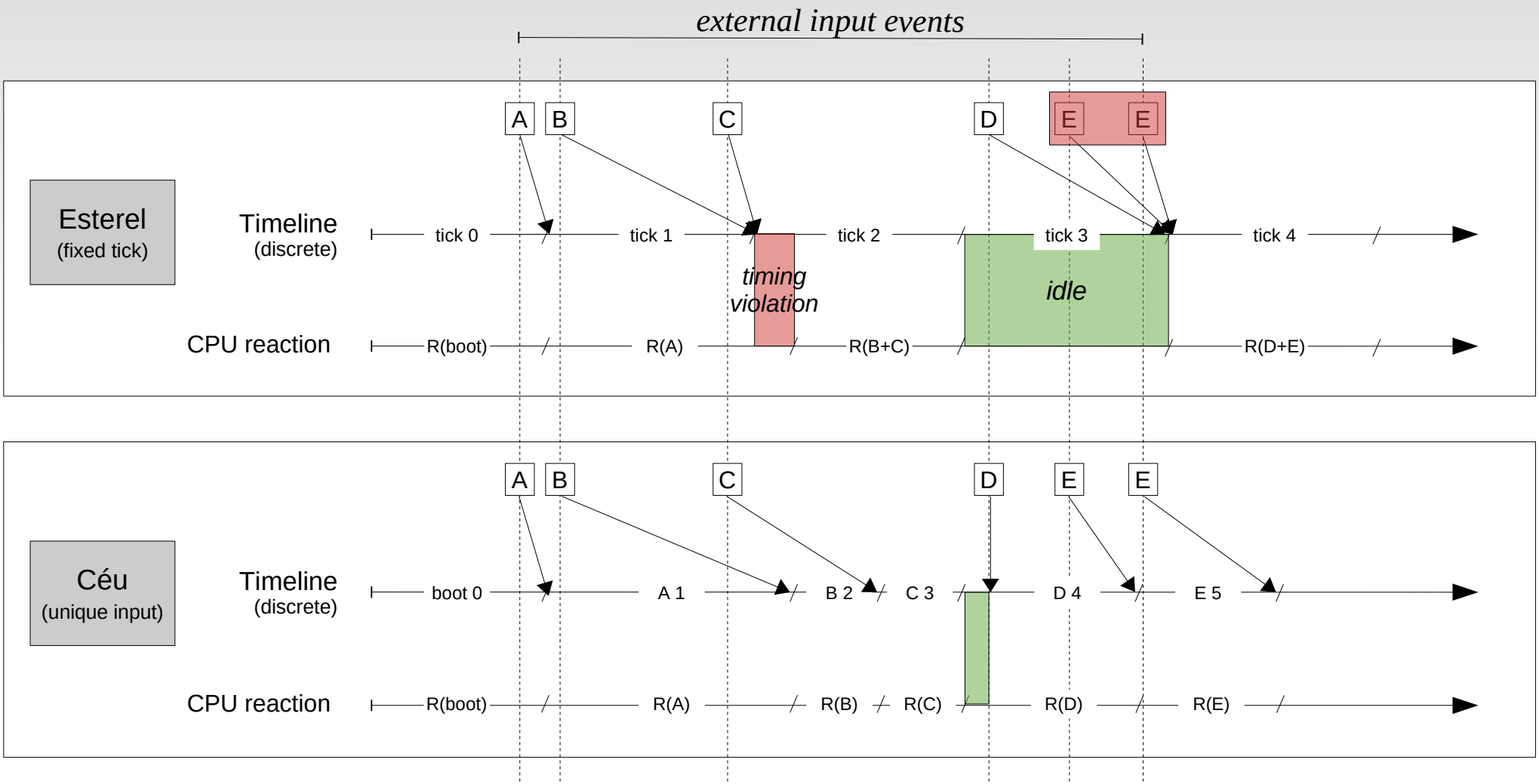

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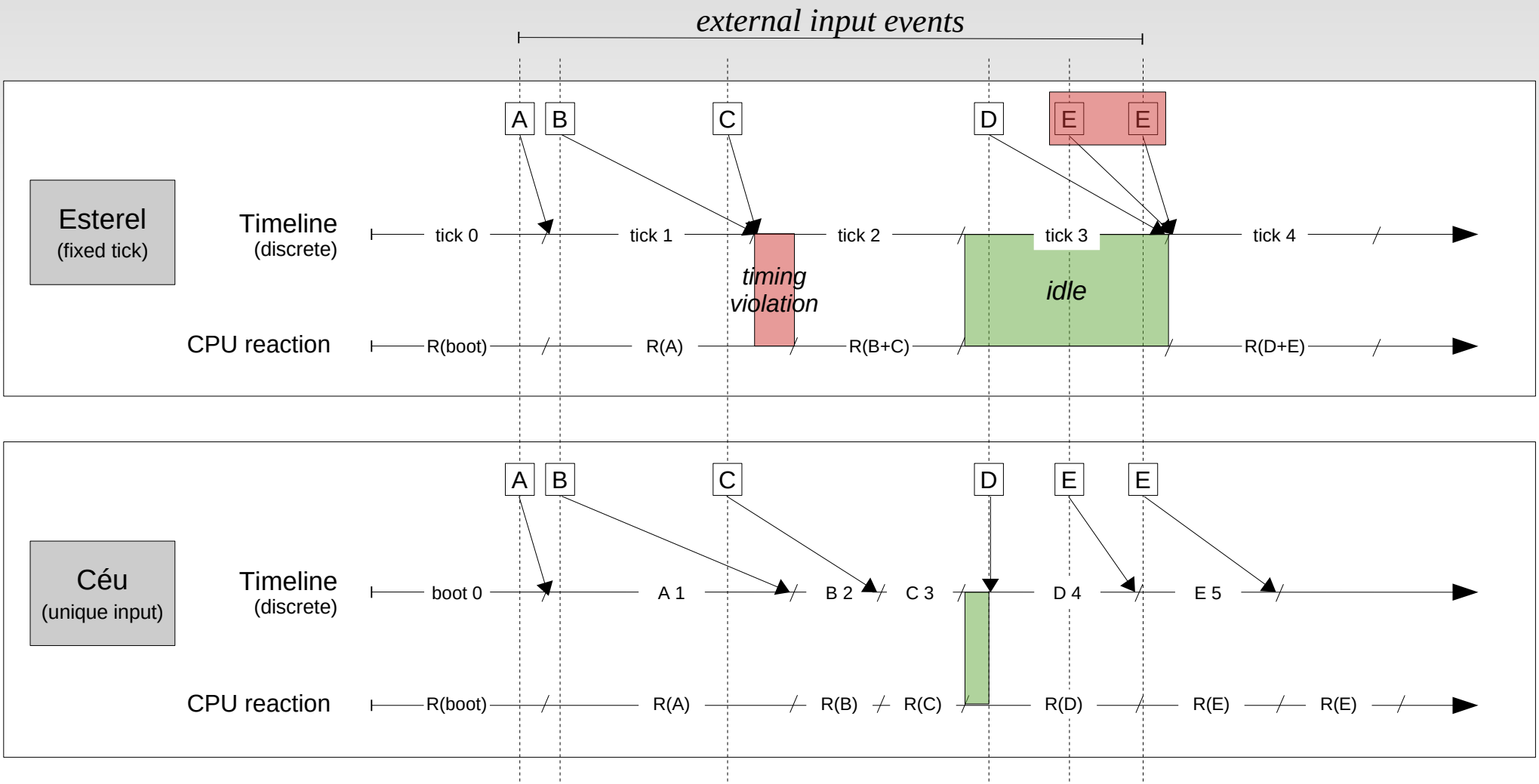

1. External Events