

An Overview of Céu

A synchronous language inspired by Esterel

Francisco Sant'Anna

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“Hello world!” in Céu

“Hello world!” in Cú

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

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- Blinking a LED

1. on ↔ off every 500ms

```
loop do
  await 500ms;
  _led_toggle();
end
```

“Hello world!” in Céu

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 1. *on ↔ off every 500ms*
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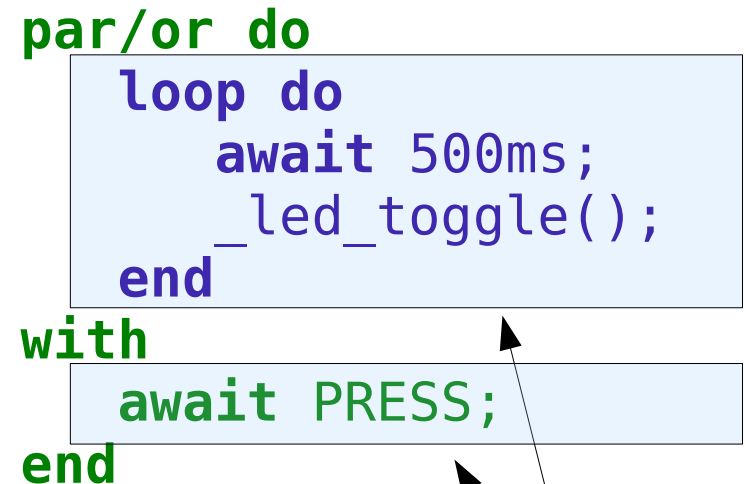
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Lines of execution
=
Trails (in Céu)

“Hello world!” in Céu

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 1. *on* ↔ *off* every 500ms
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 3. *restart* after 2s

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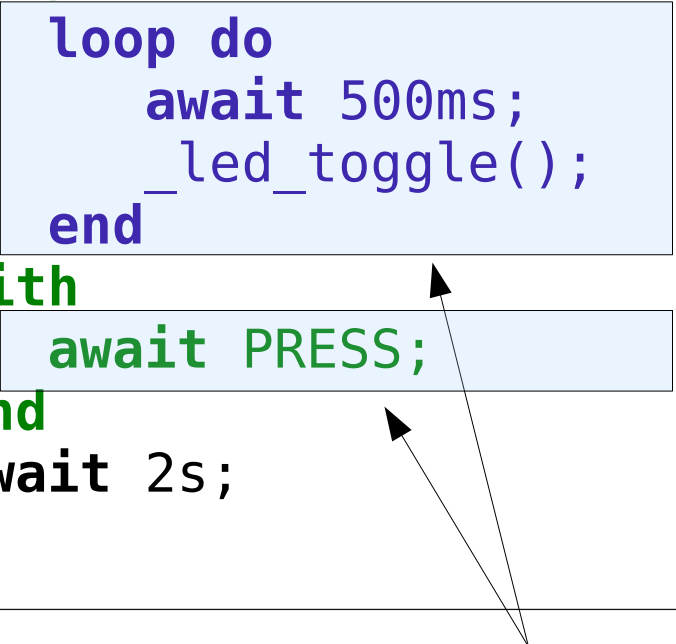


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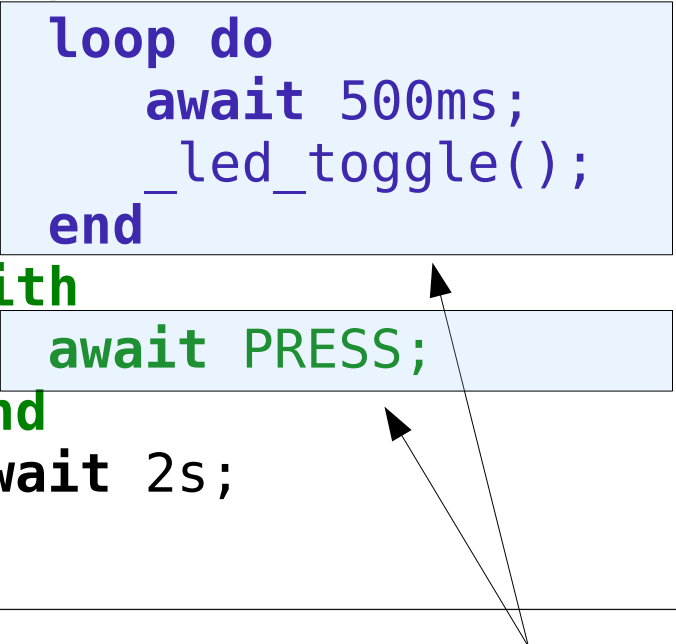


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- Compositions
 - seq, loop, par (*trails*)
 - At any level of depth

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Lines of execution
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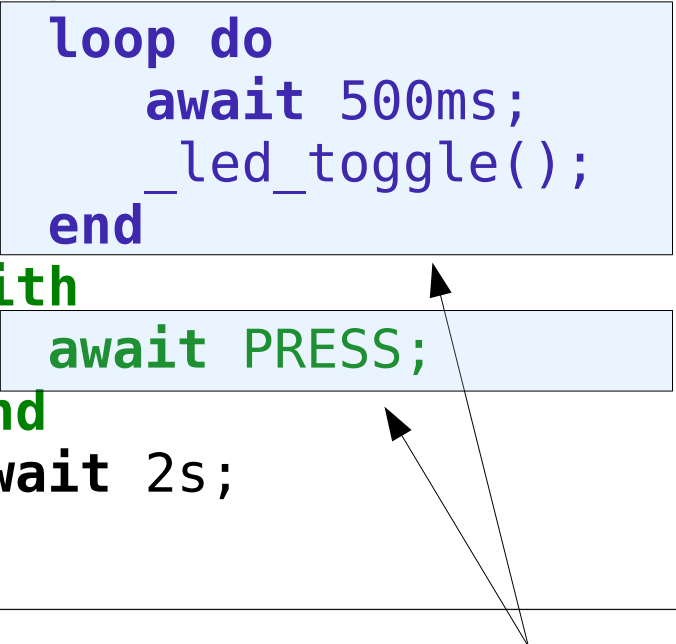
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■ Compositions

- seq, loop, par (*trails*)
 - At any level of depth
- ~~state variables / communication~~

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Lines of execution
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Trails (in Céu)

**Céu is heavily inspired
by Esterel**

Céu Peculiarities

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15 min video at ceu-lang.org

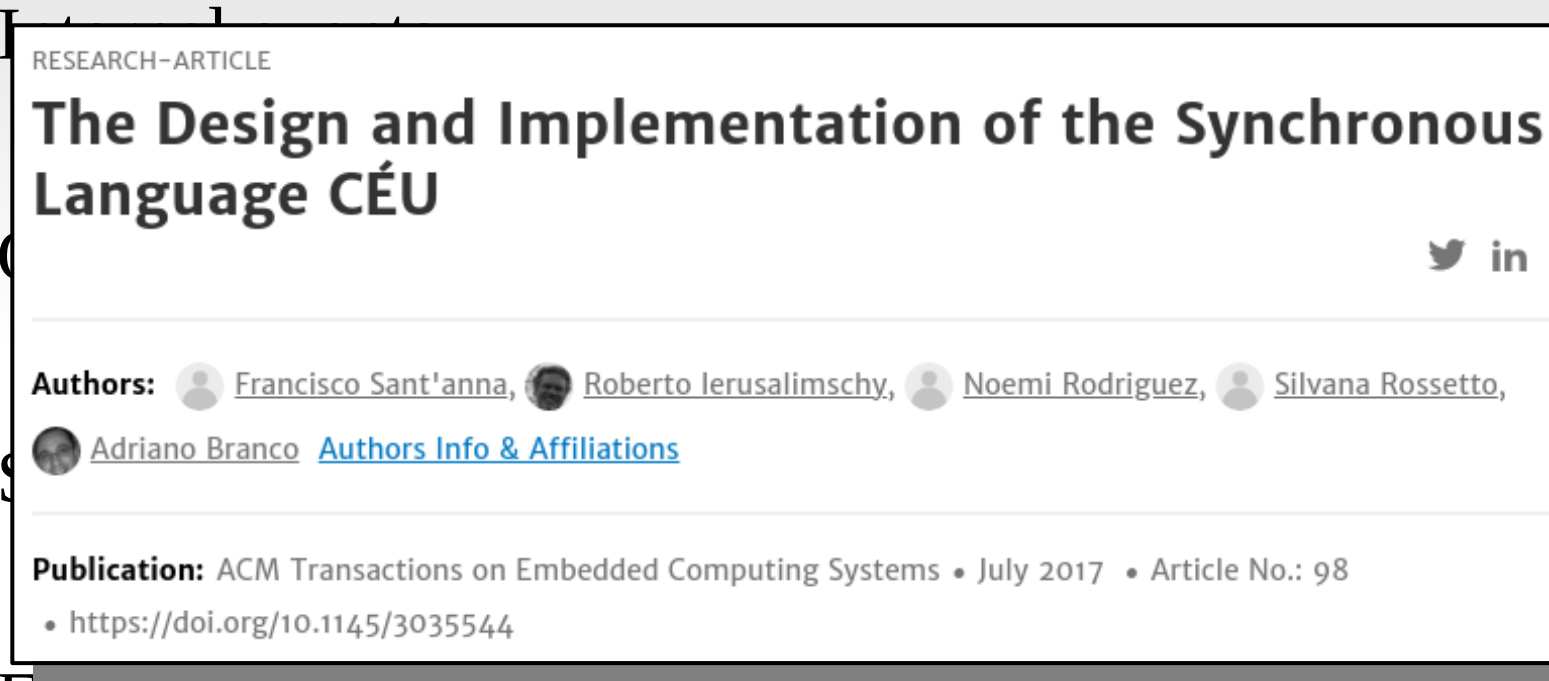
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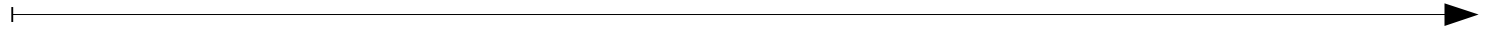
Esterel
(fixed tick)

Céu
(unique input)

1. External Events

Esterel
(fixed tick)

Timeline
(discrete)

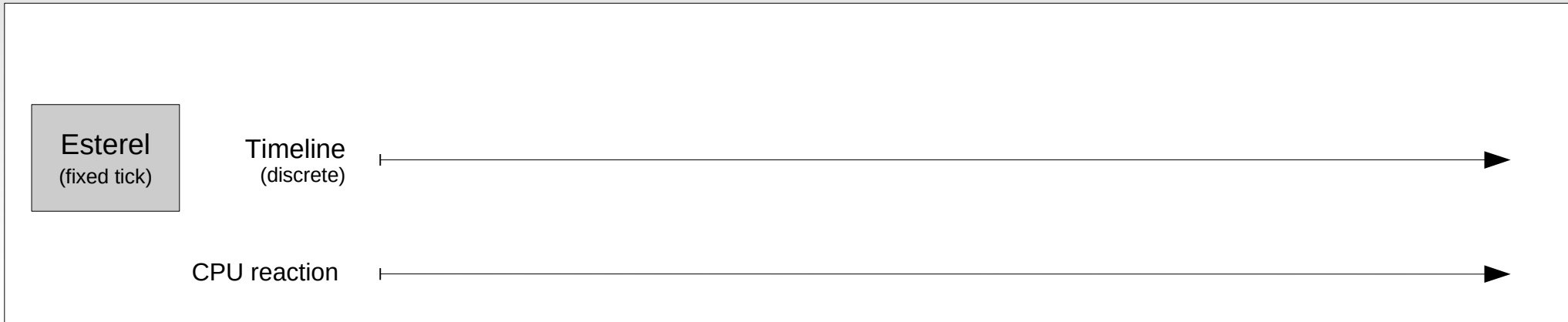


Céu
(unique input)

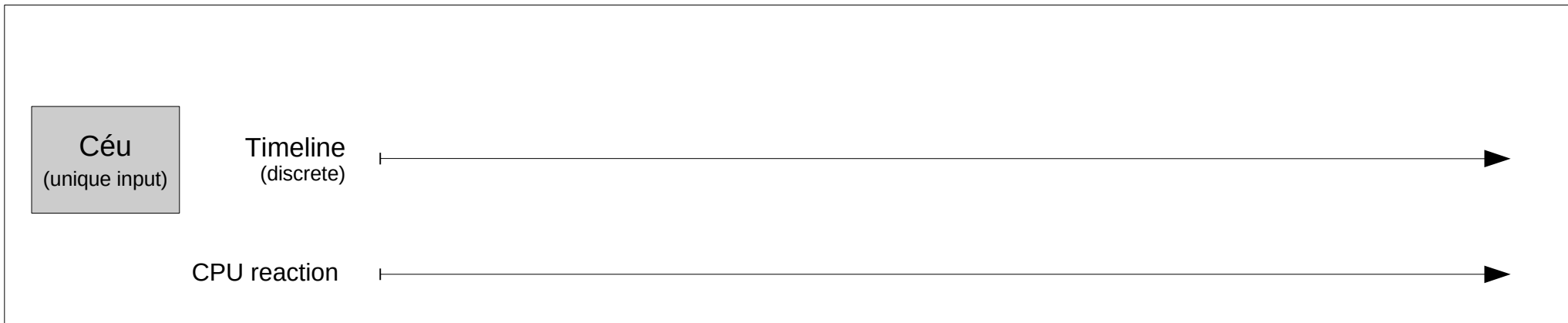
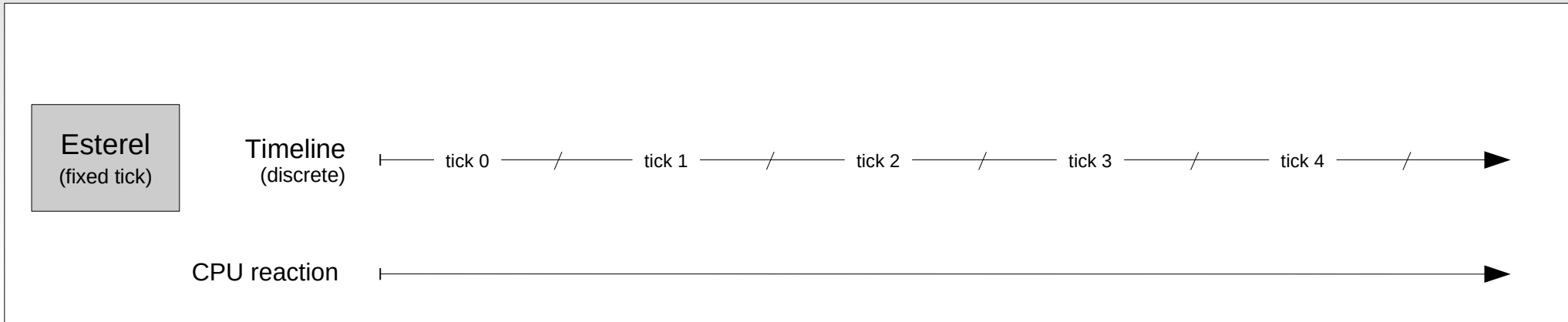
Timeline
(discrete)



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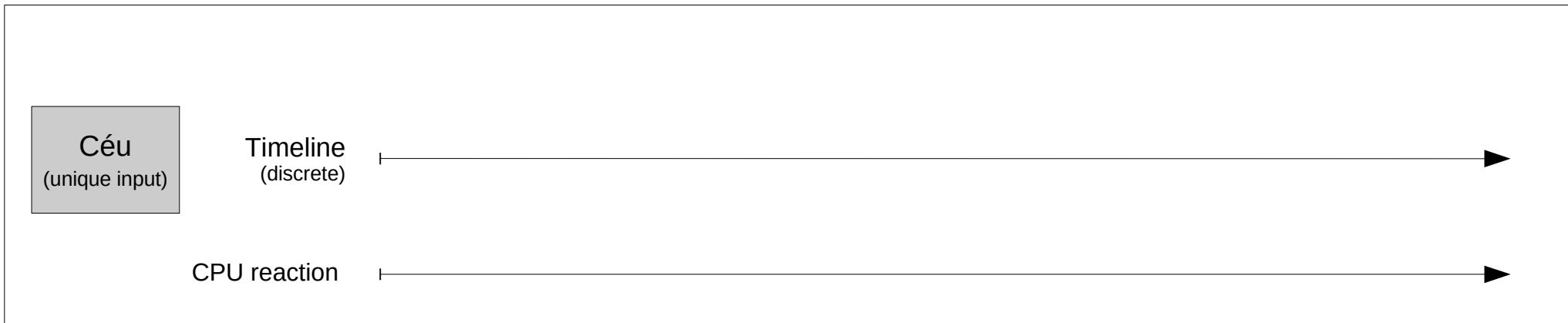
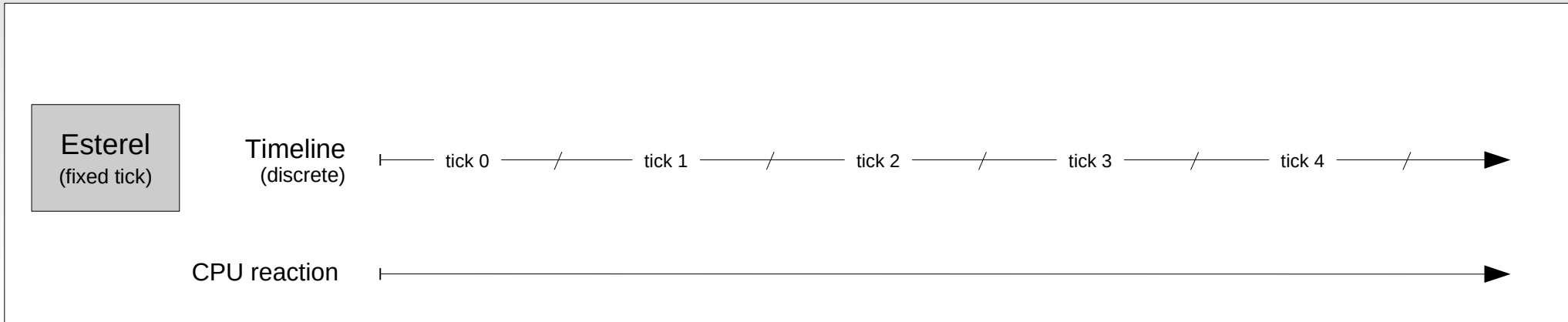


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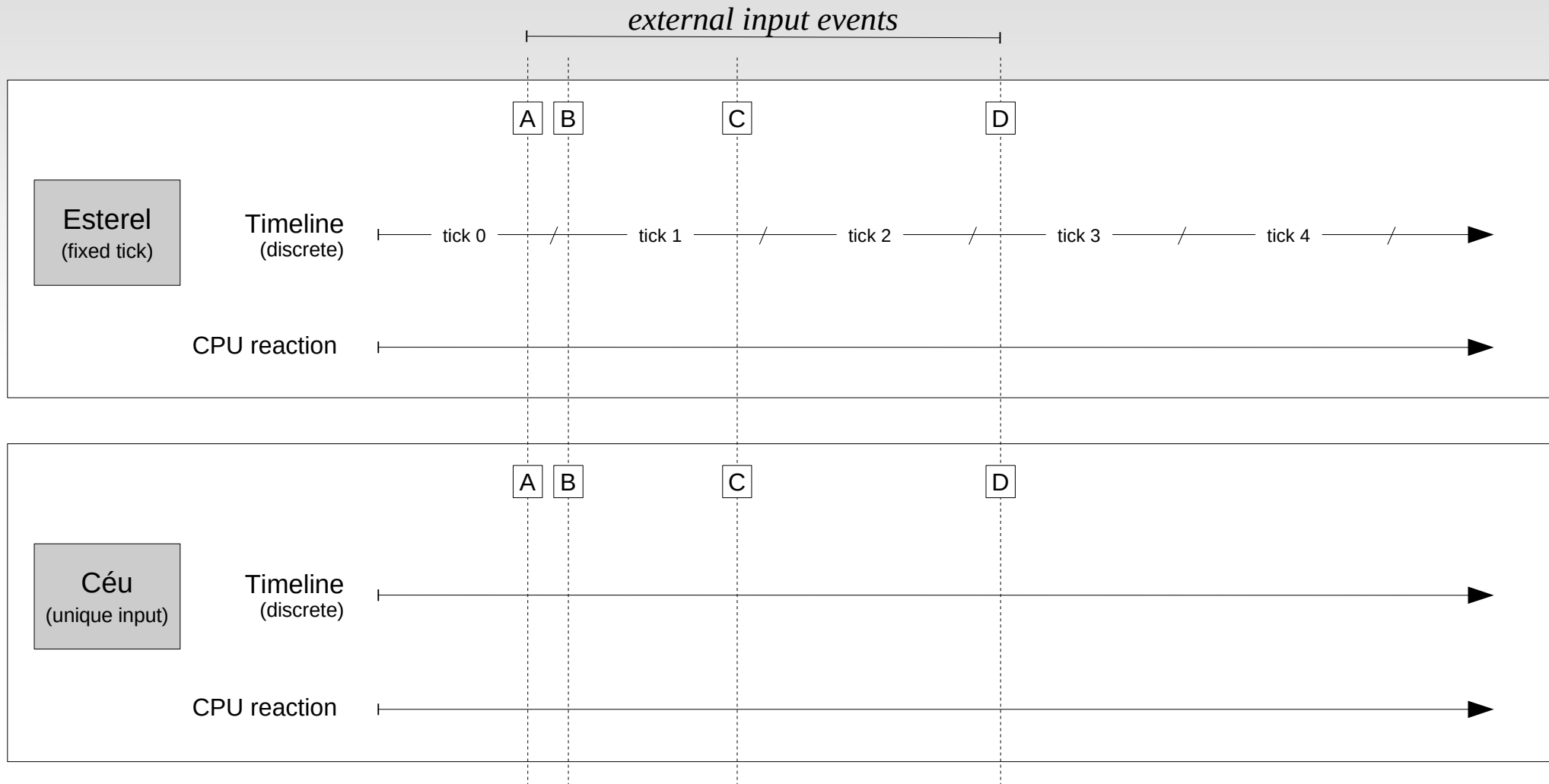


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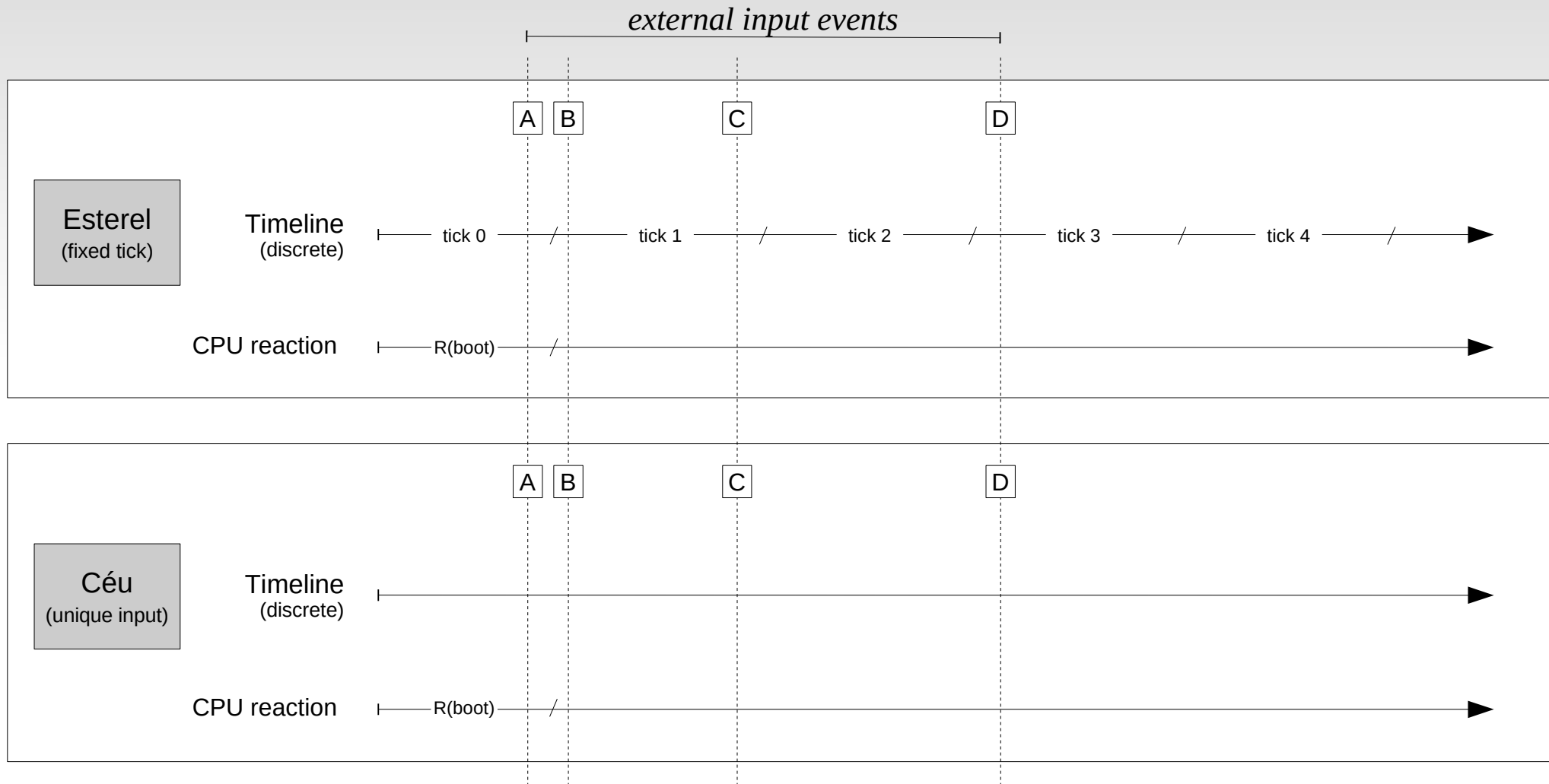
external input events



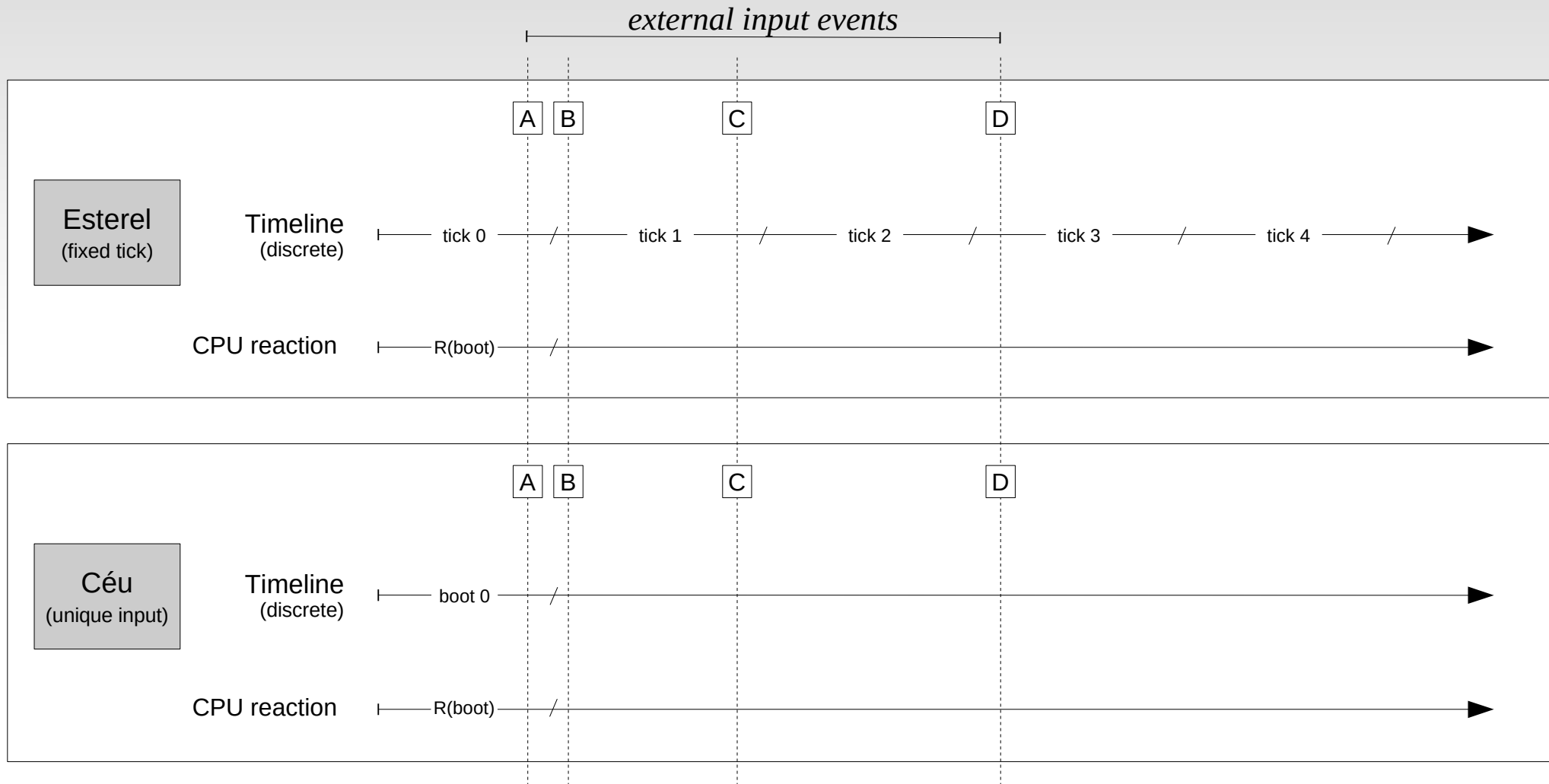
1. External Events



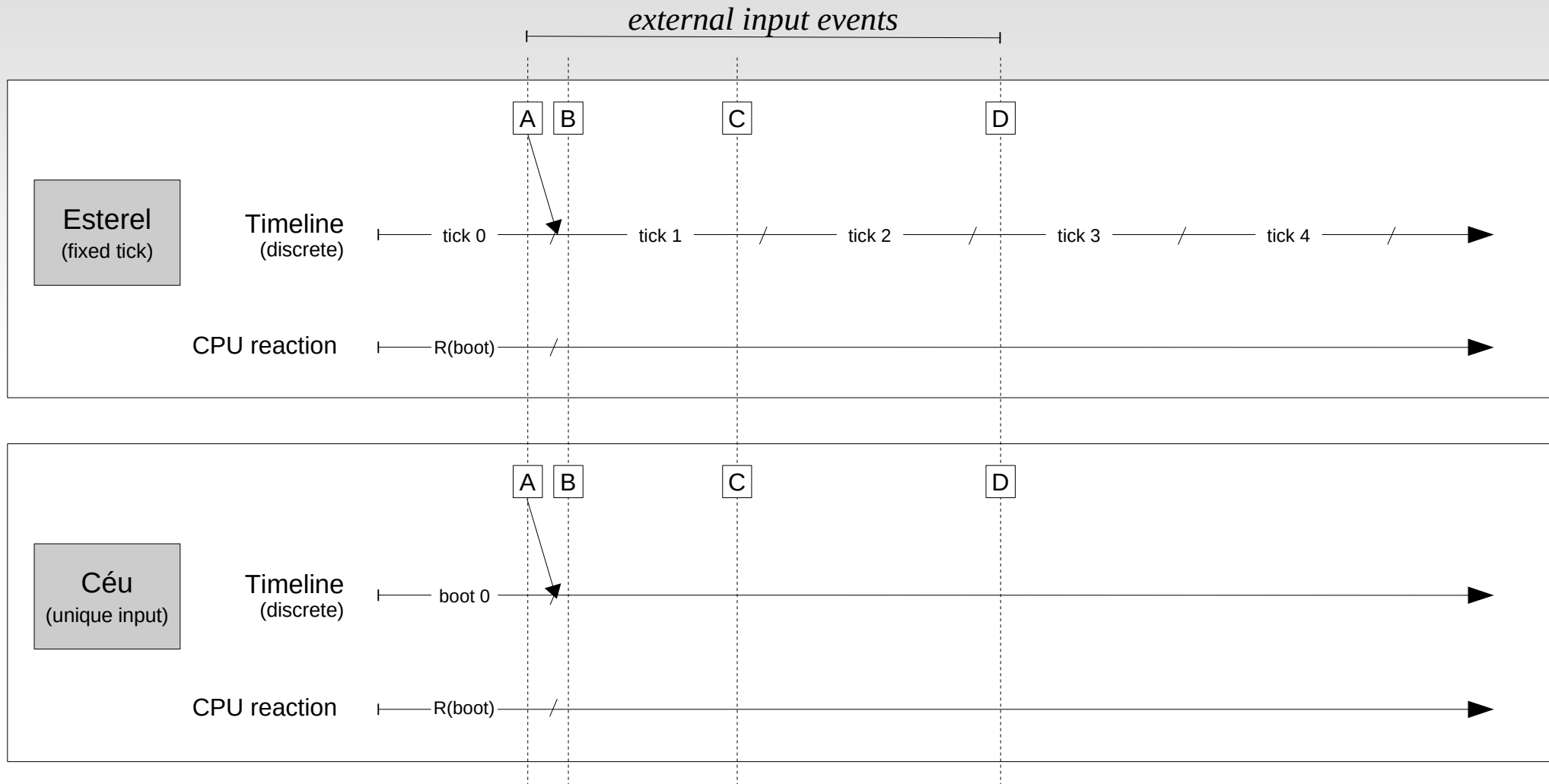
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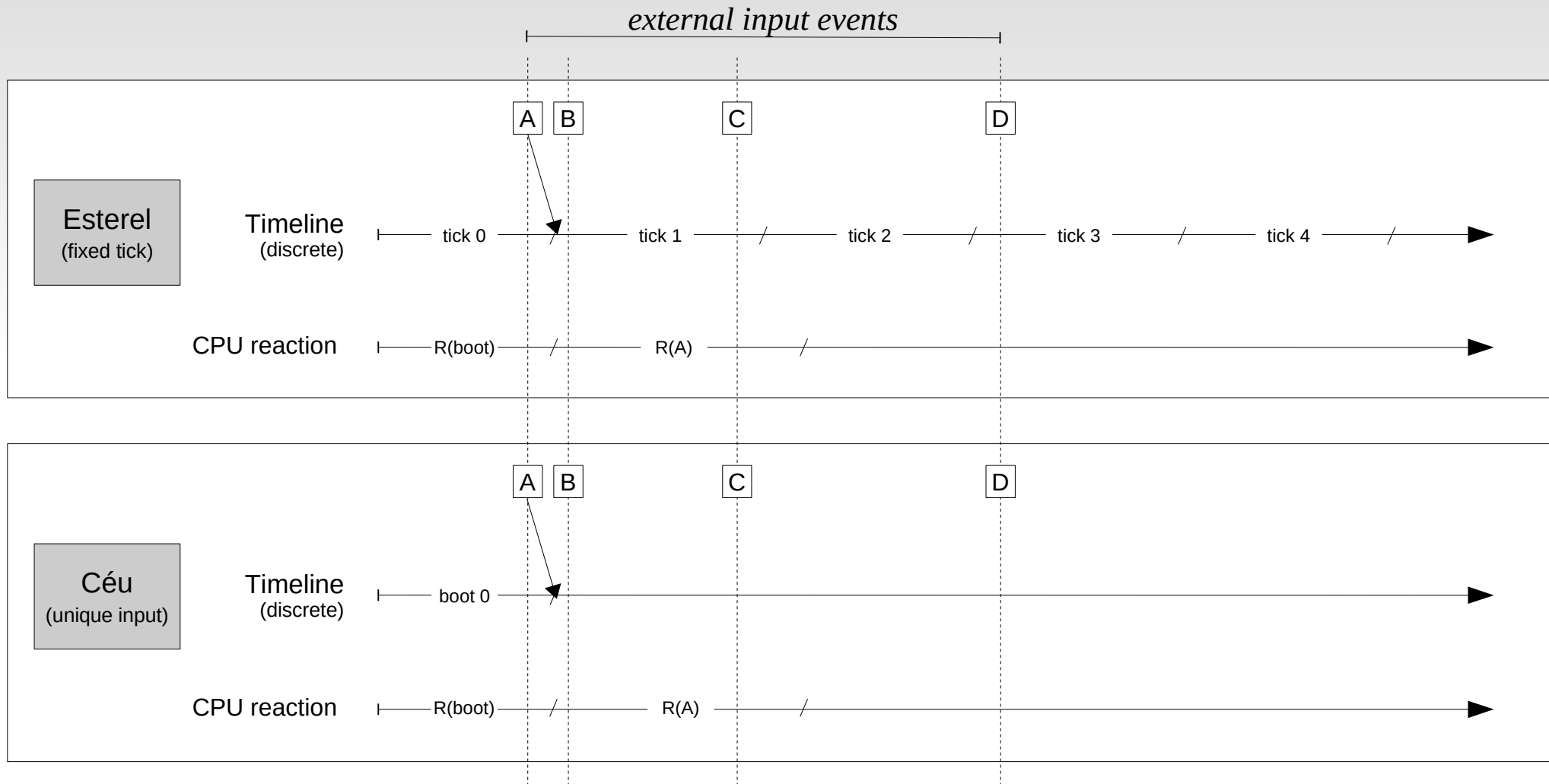
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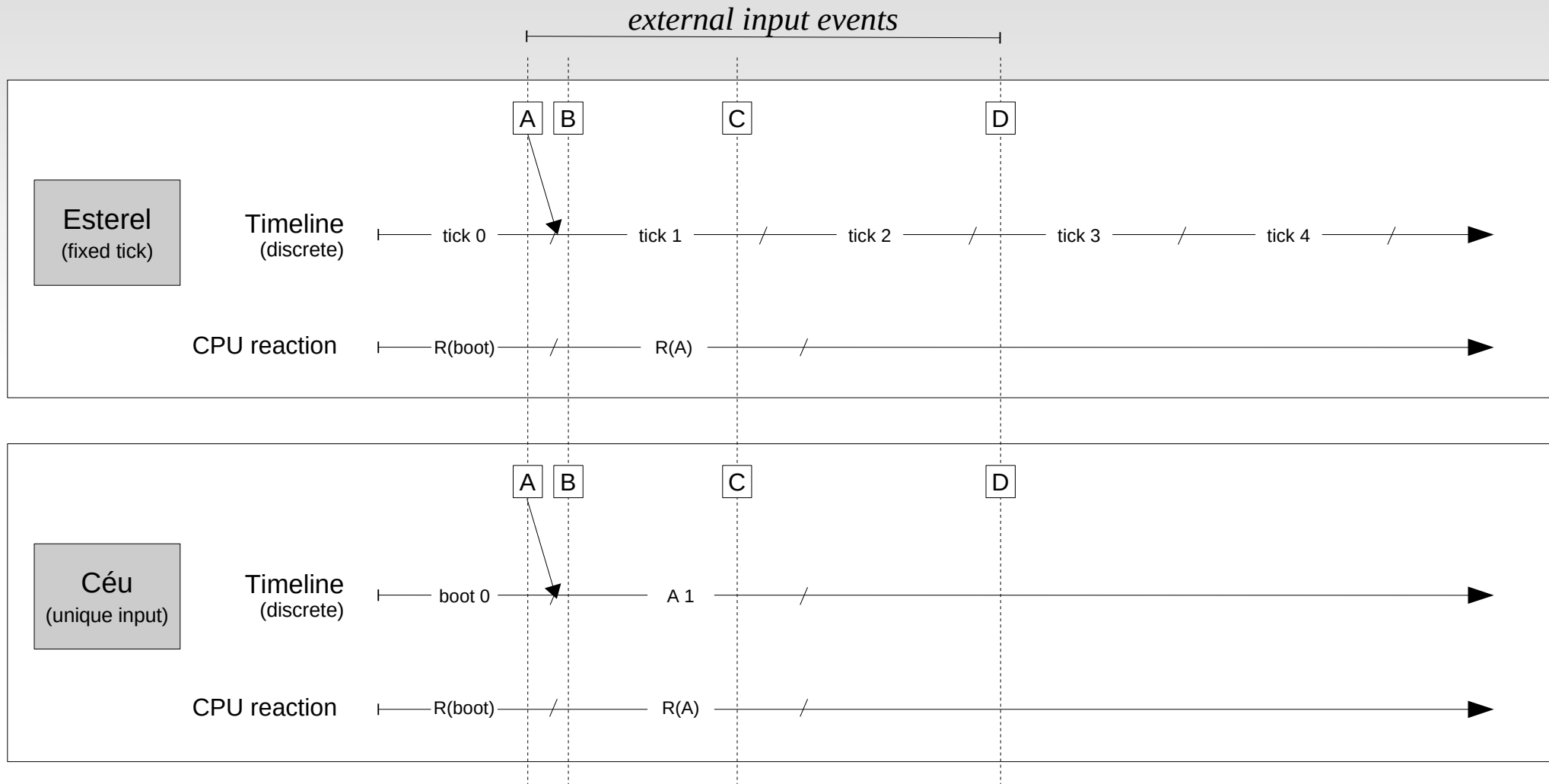
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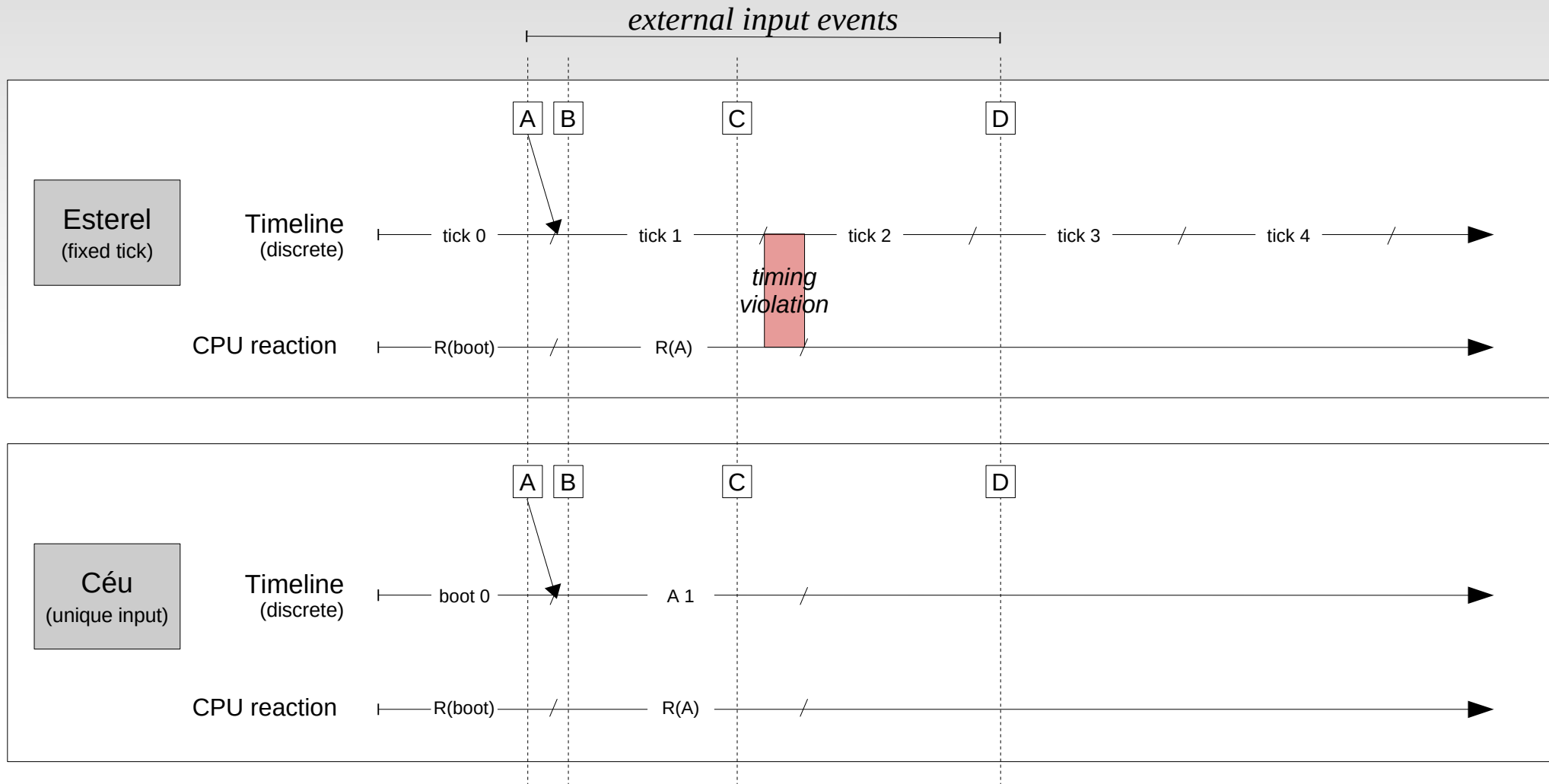
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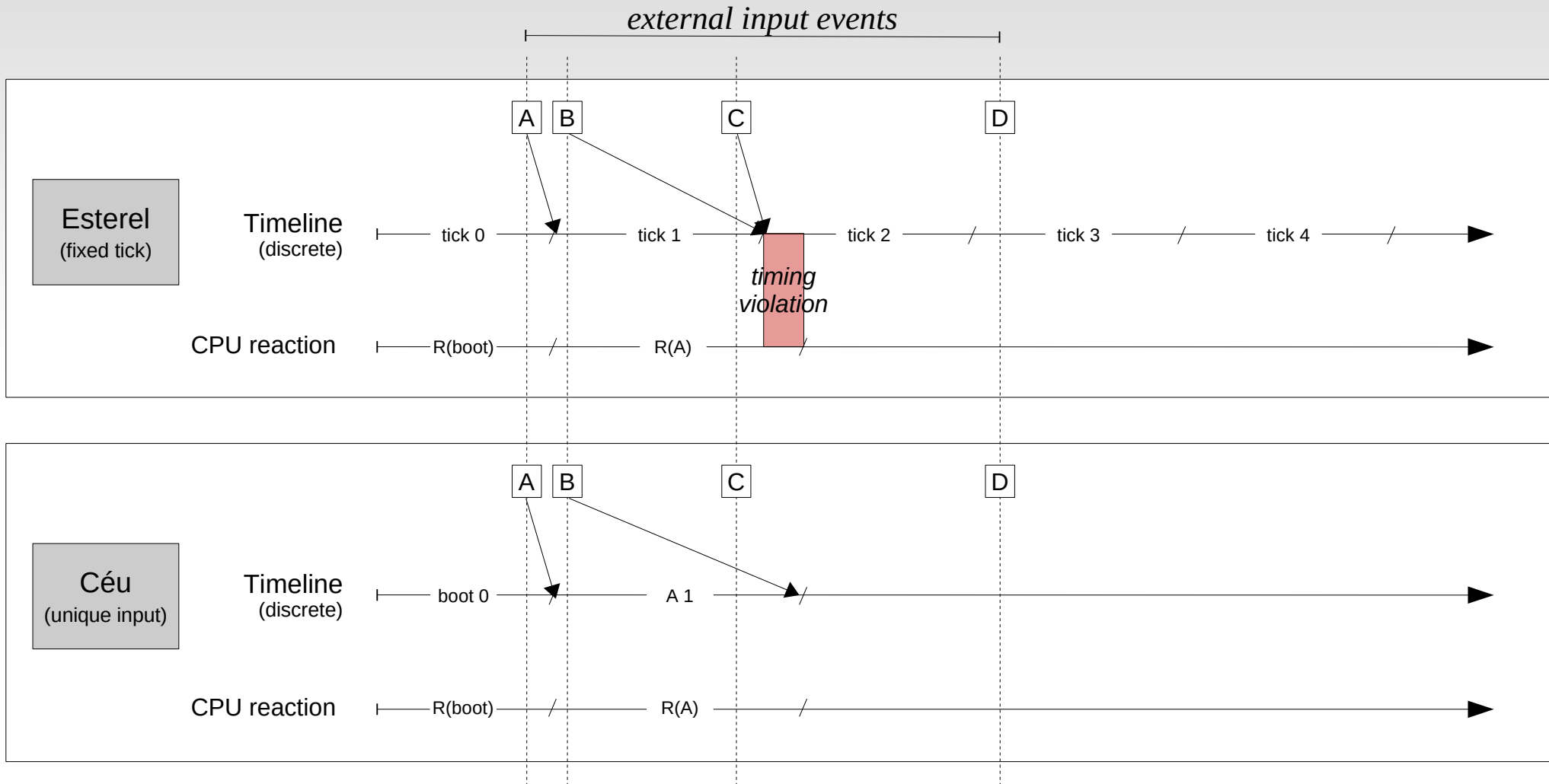
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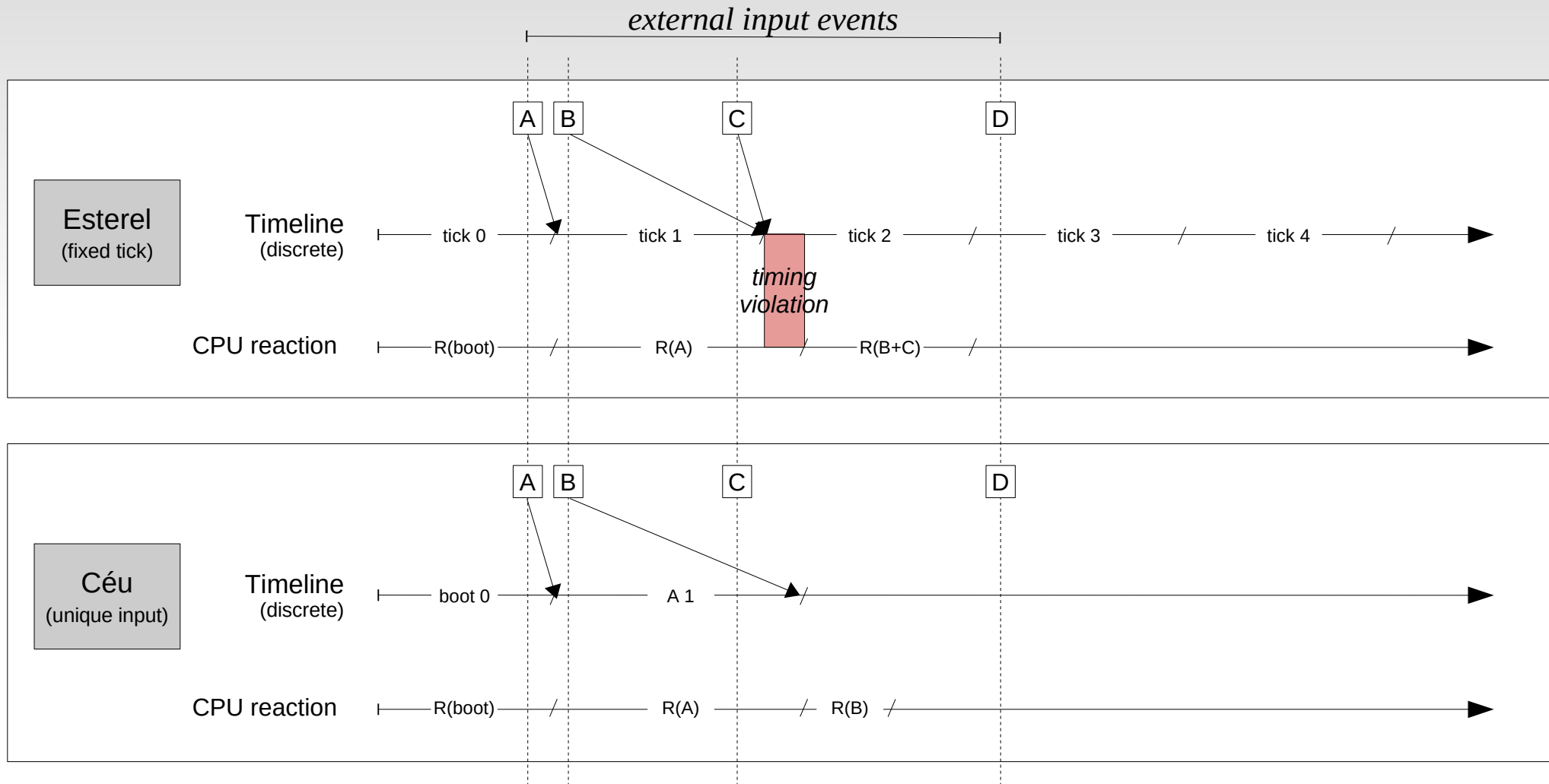
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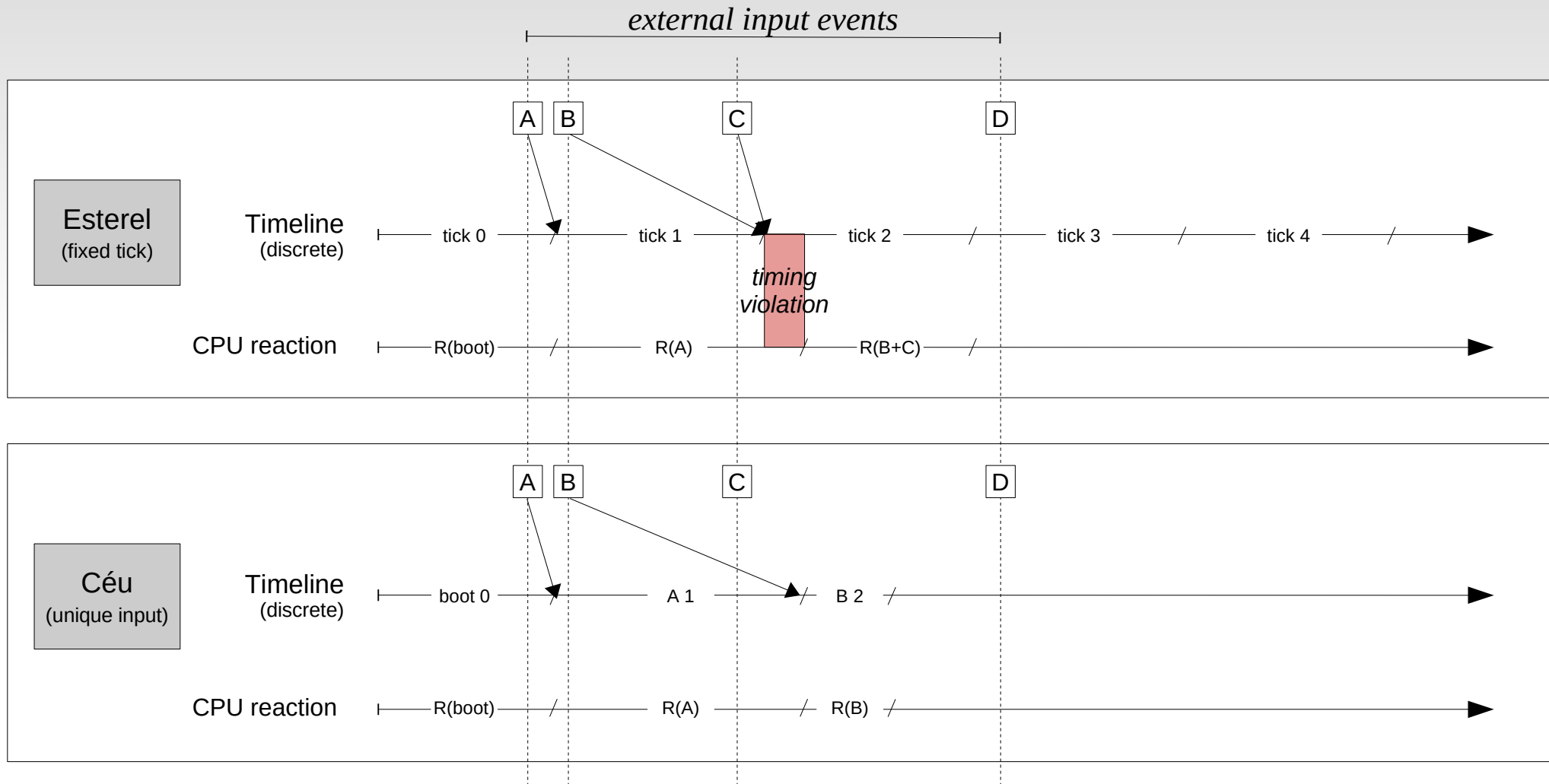
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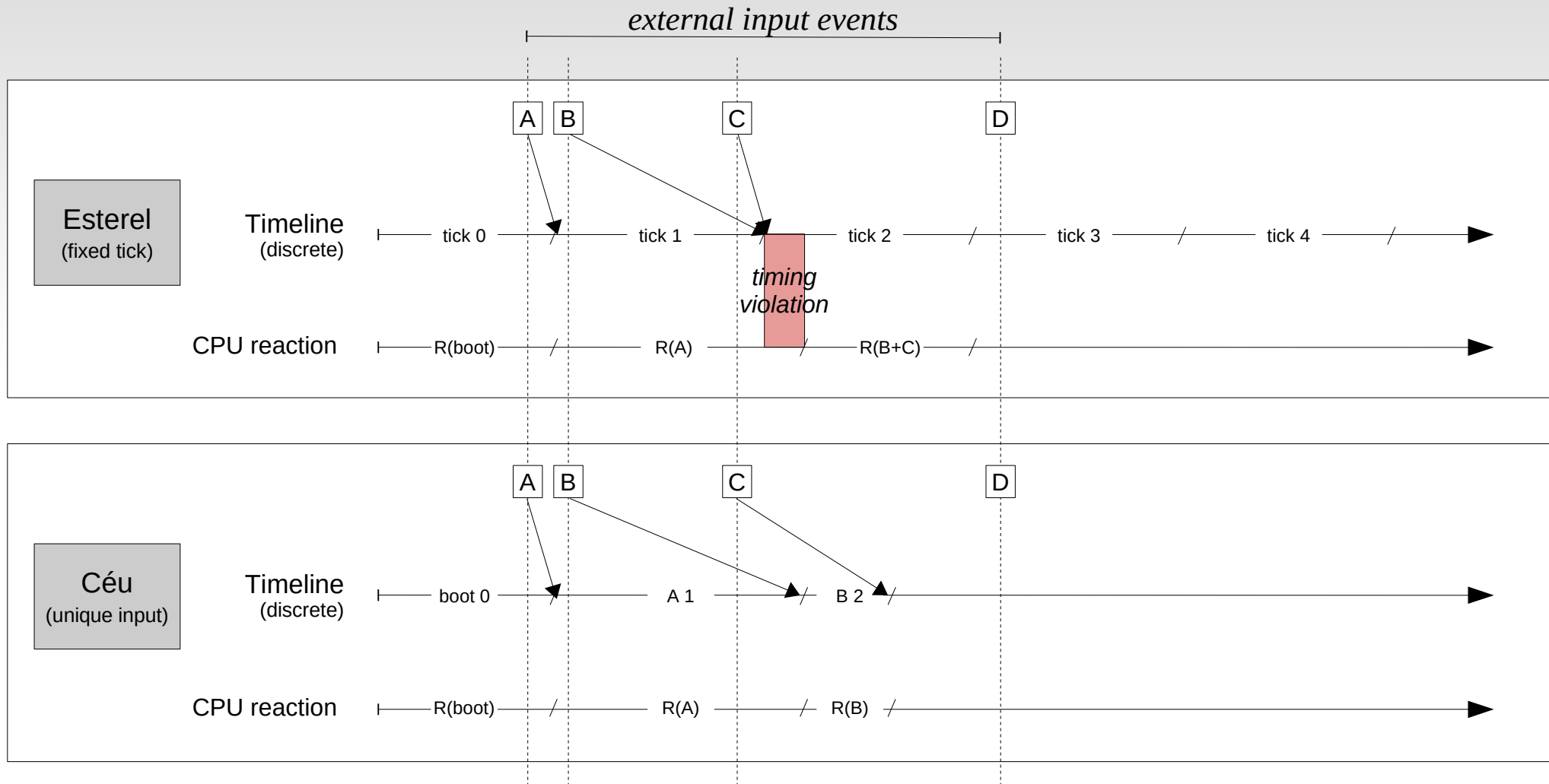
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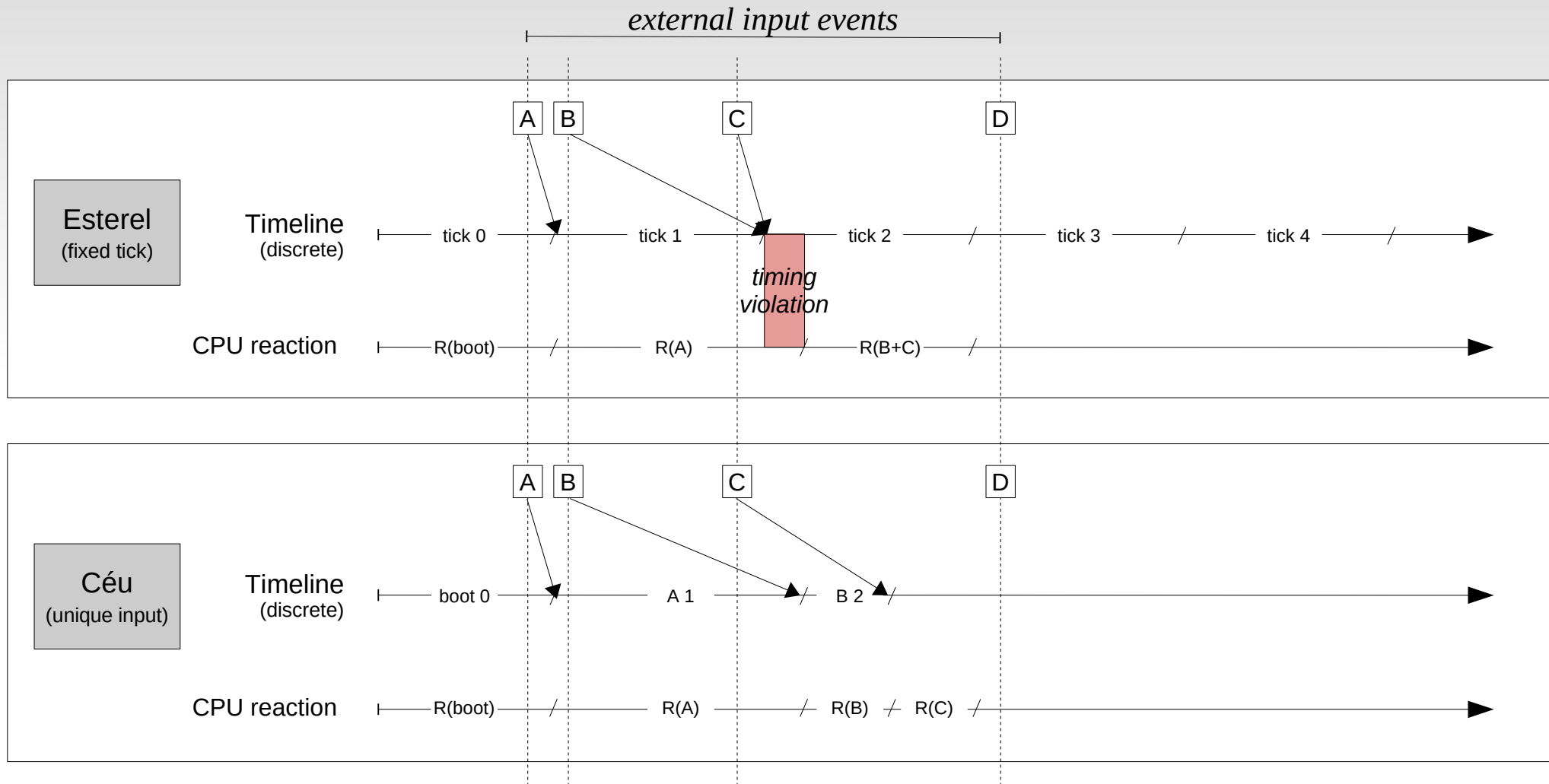
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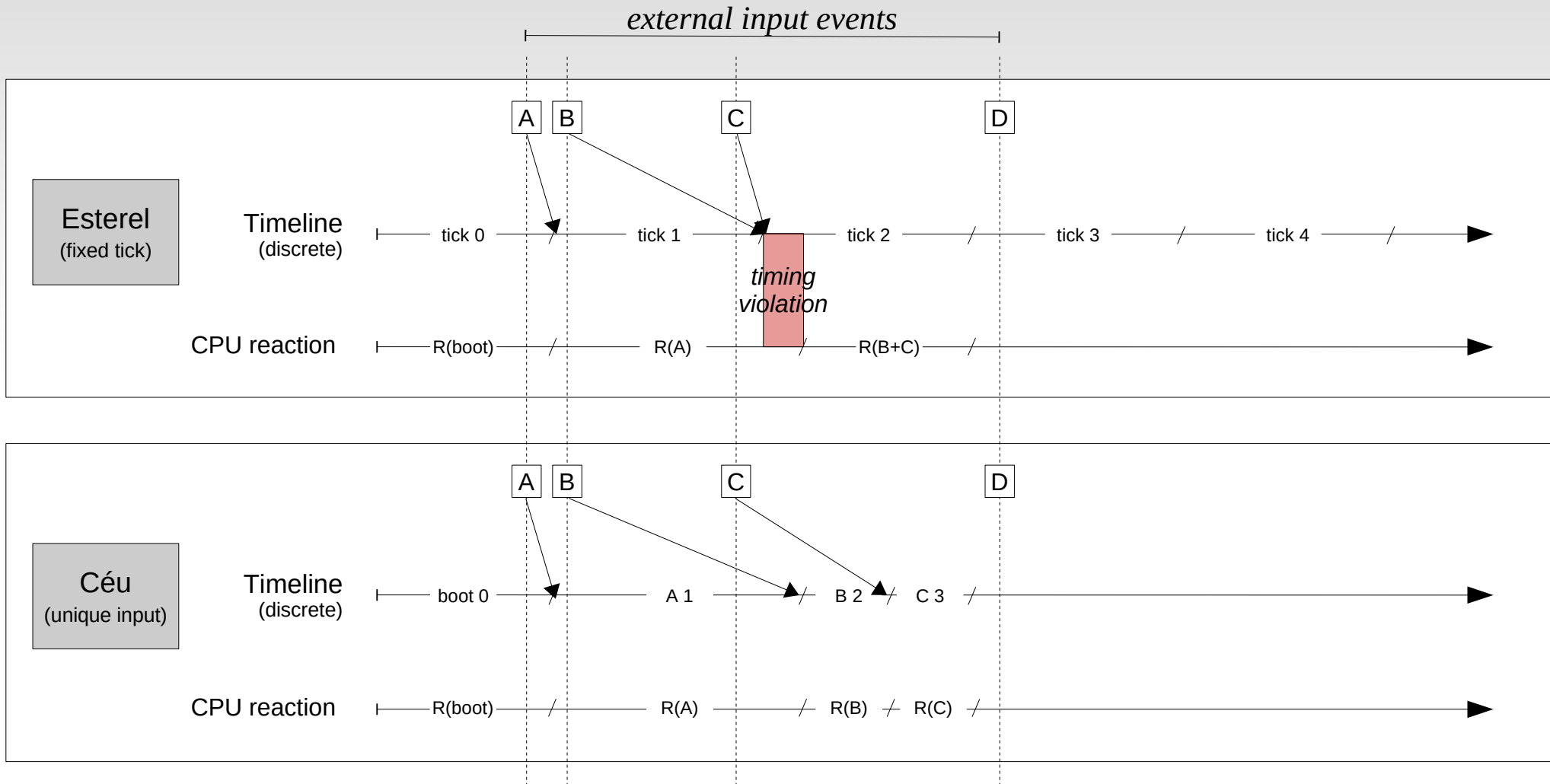
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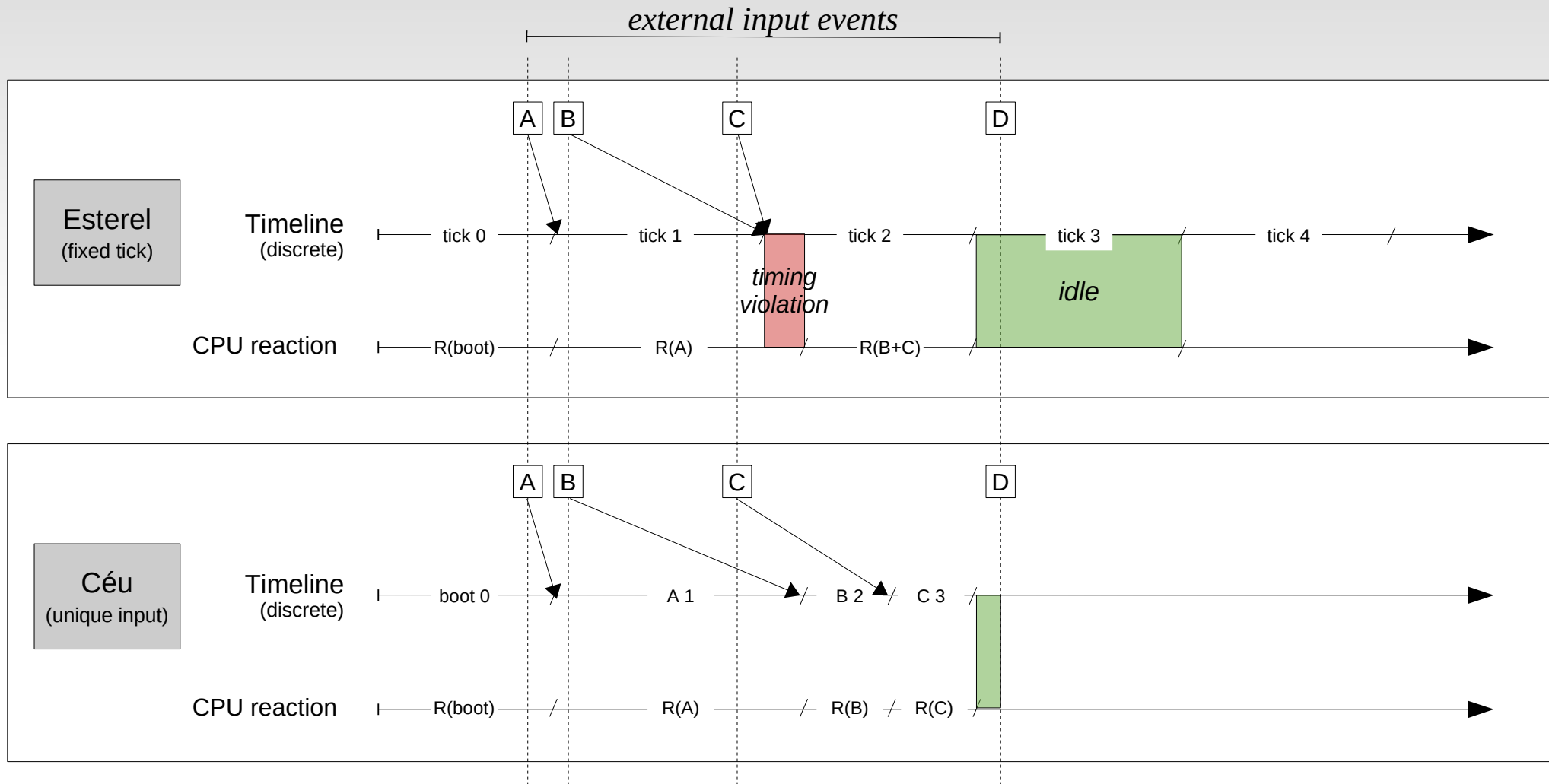
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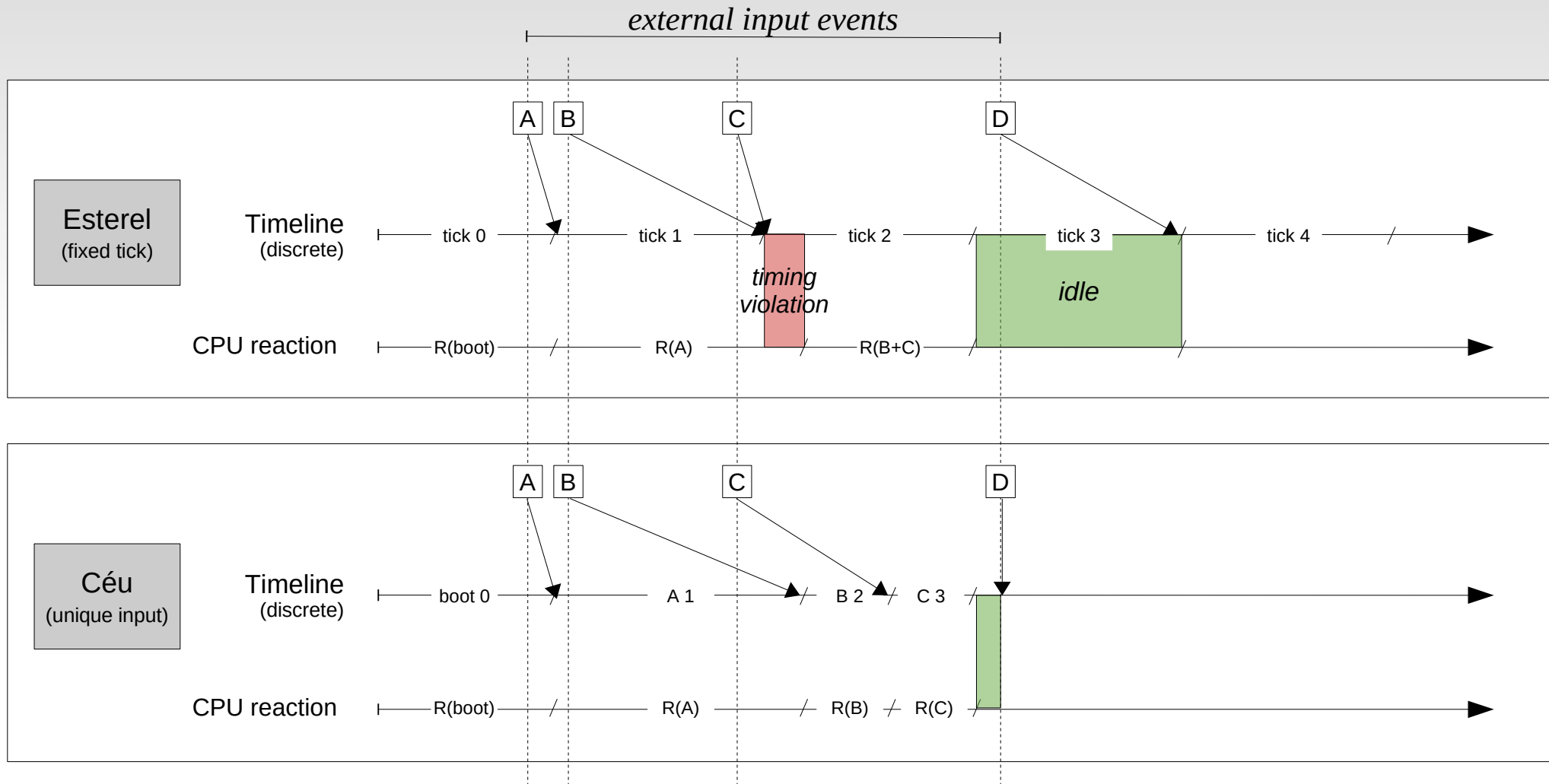
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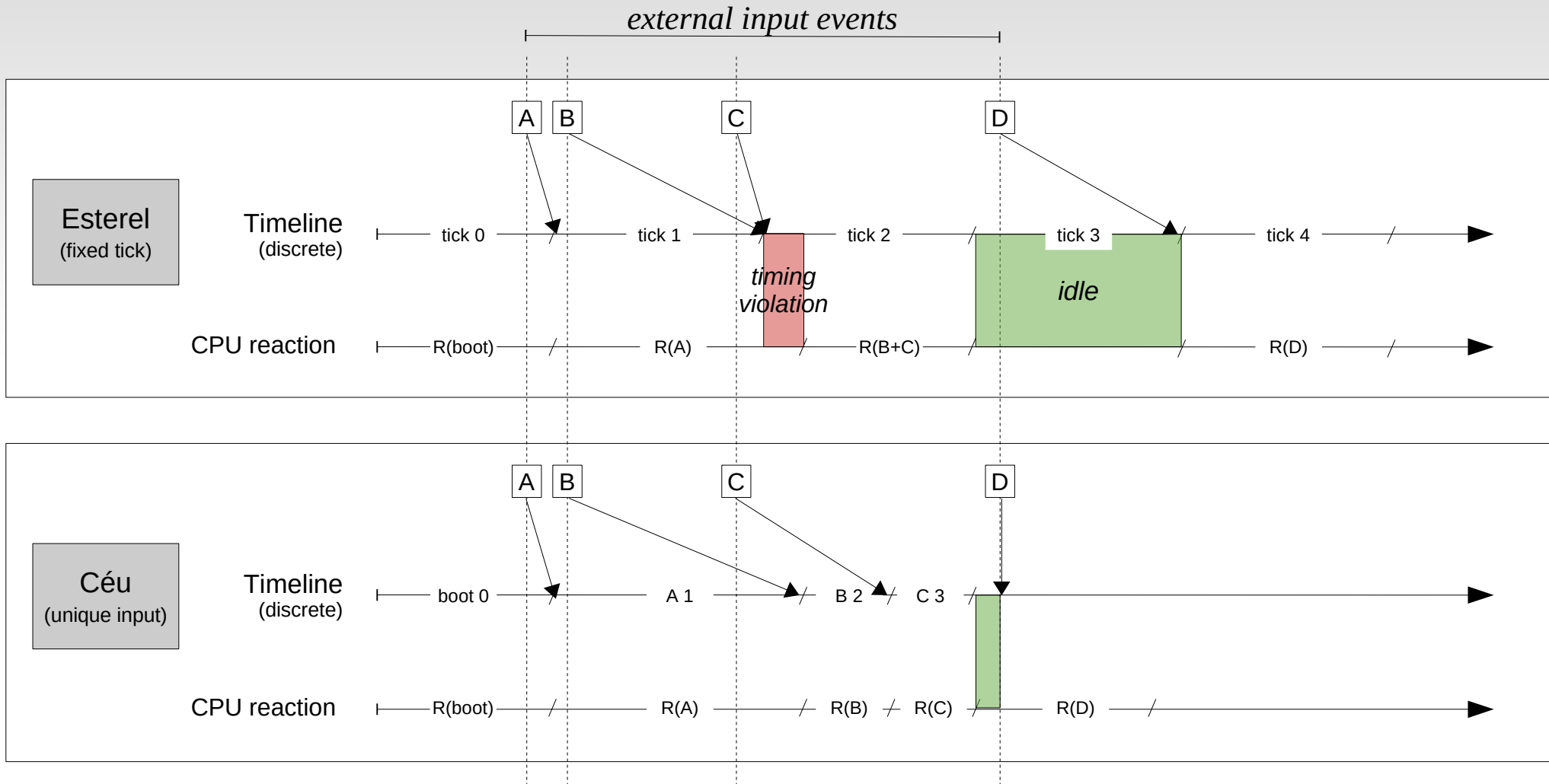
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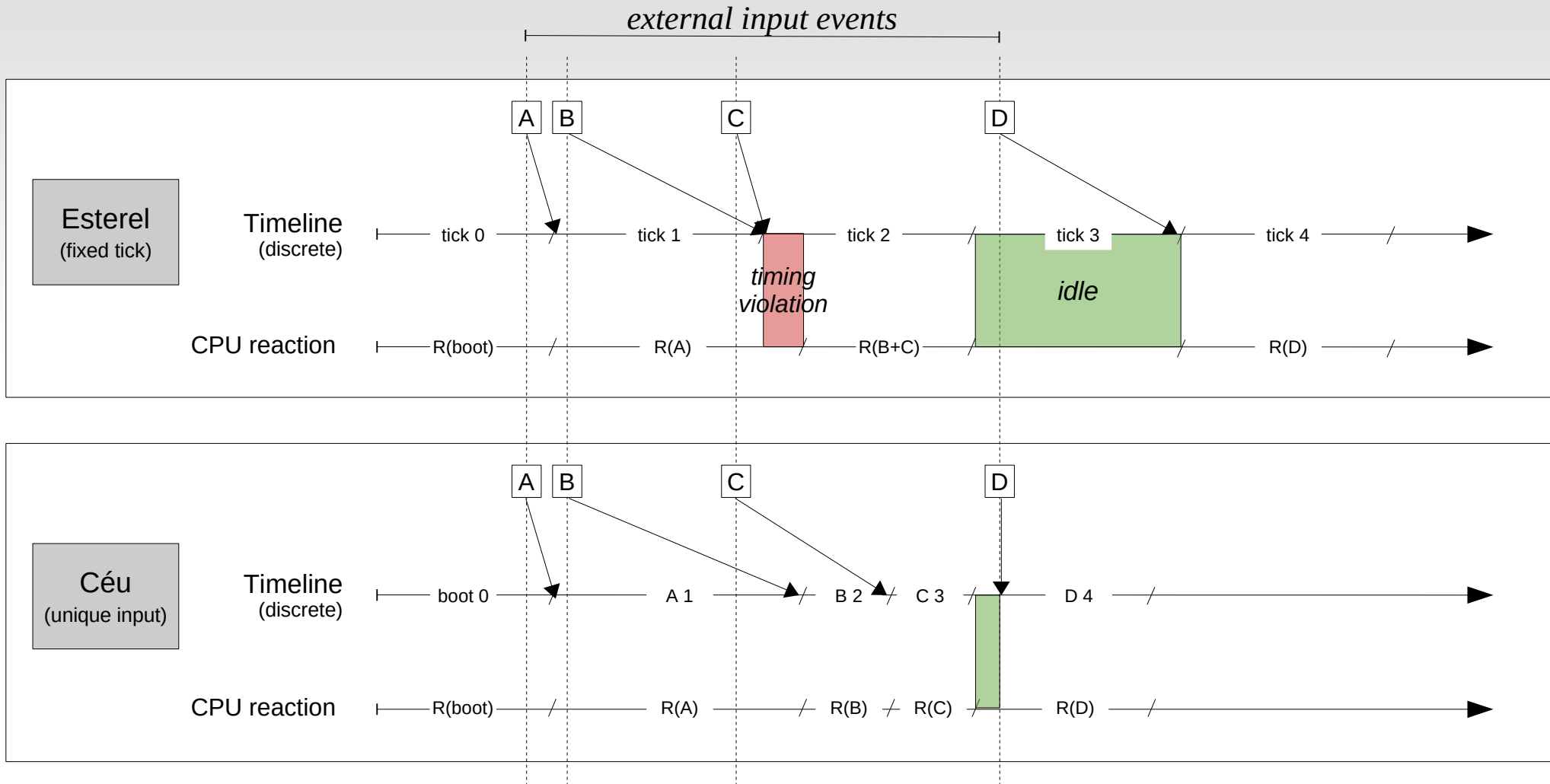
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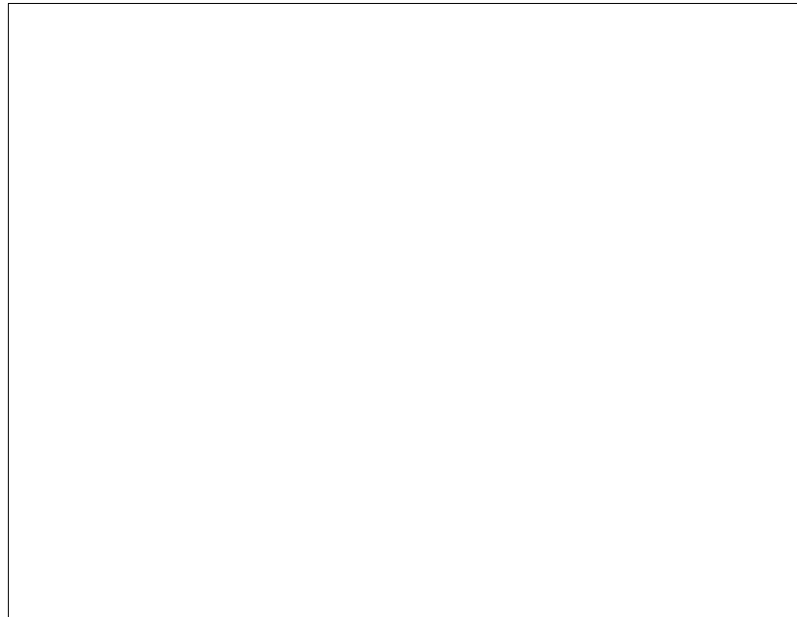
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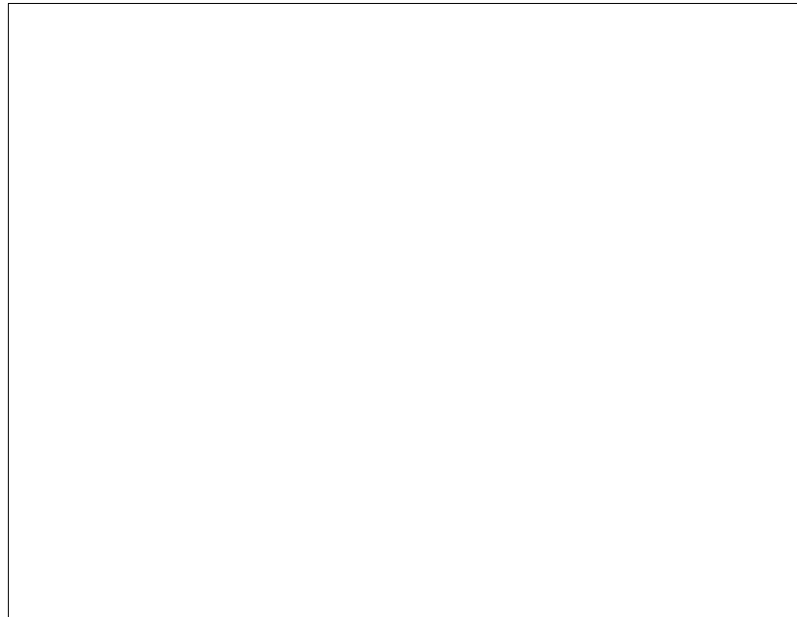


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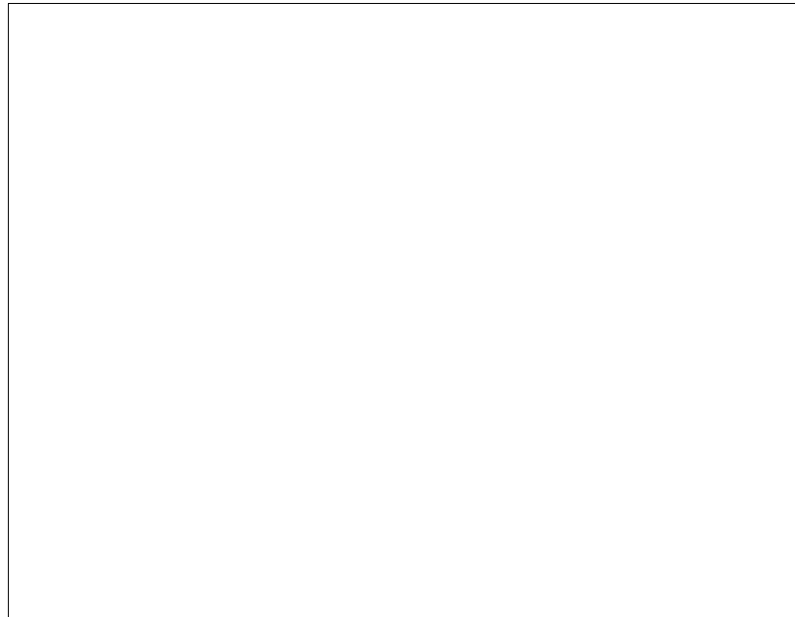
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 - an **emit** stacks next statement → awakes awaiting trails in an *intra reaction*



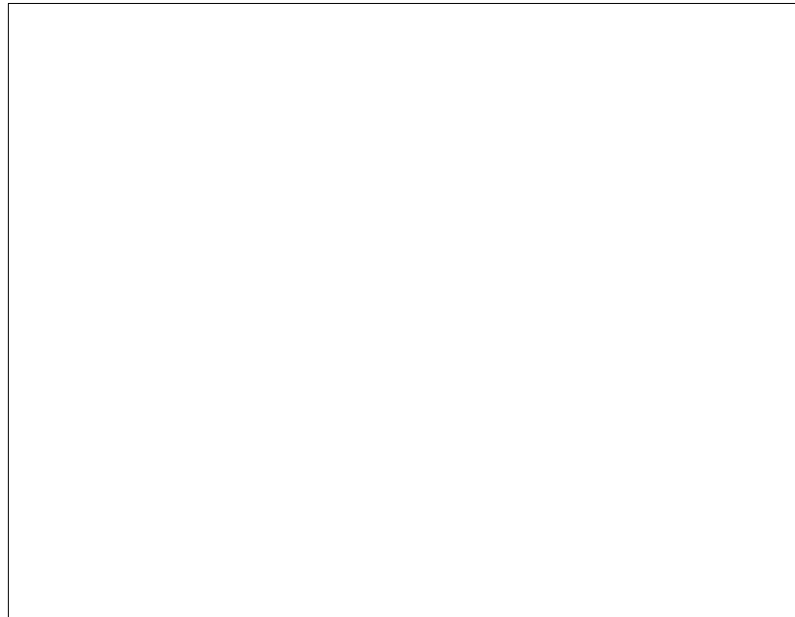
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  assert(v==2);
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    *p = *p + 1;  
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 - emits can nest (hence a stack)
- Like function calls
 - but richer: coroutines, resumable exceptions, reactive variables

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- ^① “if there is no control dependency, as in $(\text{call } f1() \parallel \text{call } f2())$, the order is unspecified and it would be an error to rely on it”
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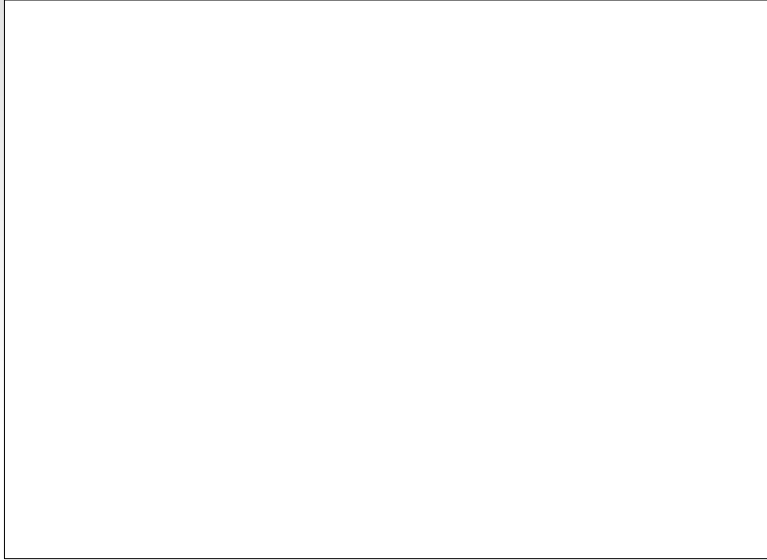
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- “if a variable is written by some thread, then it can neither be read nor be written by concurrent threads”

- Céu:

- “when multiple trails are active during the same reaction, they are scheduled in lexical order”
- pragmatic (e.g., `printf`, `redraw`), but fragile

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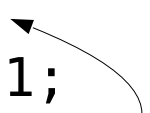
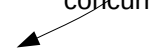
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input void A, B;  
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par/and do  
    await A;  
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with
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```
input void A, B;  
var int x = 1;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

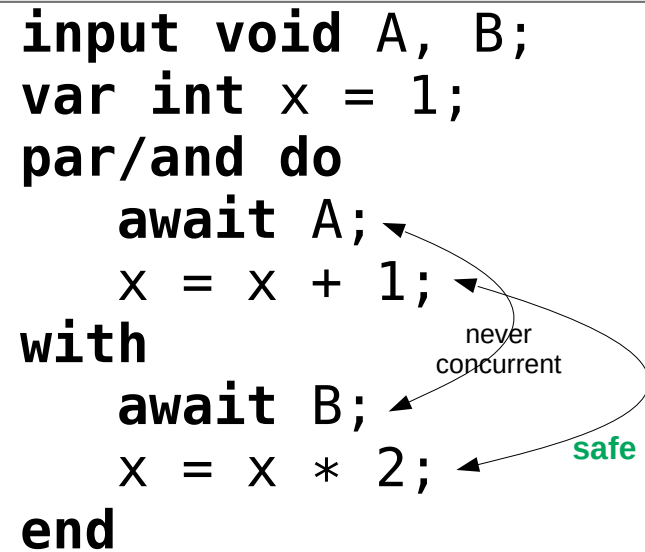
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with  
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end
```

never
concurrent

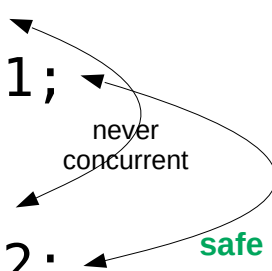
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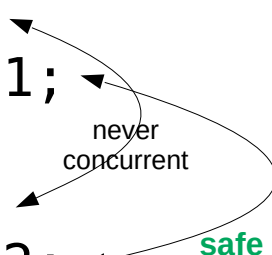
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  await B;  
  x = x * 2;  
end
```



The diagram illustrates a static check on the provided code. A curved arrow originates from the statement `x = x * 2;` within the `with` block and points back to the `await A;` statement within the `par/and do` block. This arrow is labeled with the text "never concurrent" and "safe", indicating that the code is statically checked for safety and concurrency.

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
```

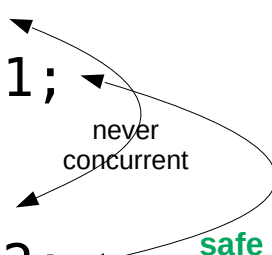


The diagram illustrates a static check for concurrency. A curved arrow originates from the line `x = x * 2;` and points back to the line `x = x + 1;`. The text "never concurrent" is written above the arrow, and the word "safe" is written in green below the arrow.

```
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  
  await B;  
  x = x * 2;  
end
```

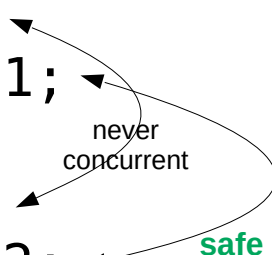


The diagram illustrates a static check for concurrency. A curved arrow originates from the statement `x = x * 2;` in the `with` block and points back to the `await A;` statement in the `par/and do` block. The text "never concurrent" is written above the arrow, and the word "safe" is written in green below the arrow.

```
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
```

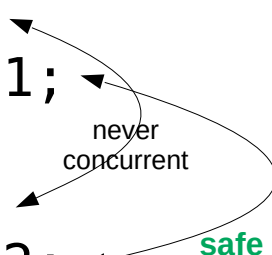


The diagram illustrates a static check for concurrency. A curved arrow originates from the statement `x = x * 2;` in the `with` block and points back to the `await A;` statement in the `par/and do` block. The arrow is labeled "never concurrent" and "safe".

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

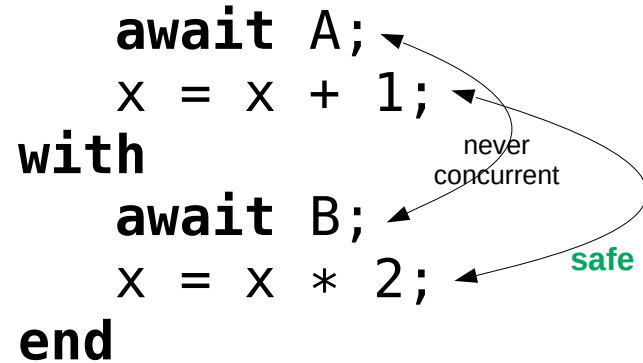


never concurrent
safe

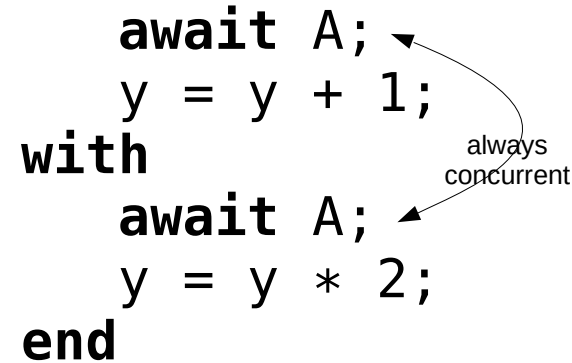
```
input void A;  
var int y = 1;  
par/and do  
  await A;  
  y = y + 1;  
with  
  await A;  
  y = y * 2;  
end
```

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

```
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

unsafe

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

unsafe

- 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
```

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
```

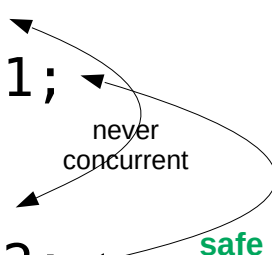
always concurrent

unsafe

- Static checks
 - Level 0: both are refused

3. Simple Static Checks

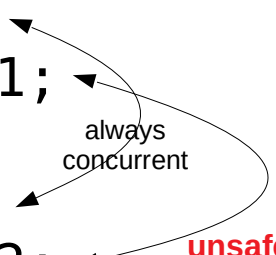
```
input void A, B;  
var int x = 1;  
par/and do  
  await A;  
  x = x + 1;  
with  
  await B;  
  x = x * 2;  
end
```



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

unsafe

- 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
```

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
```

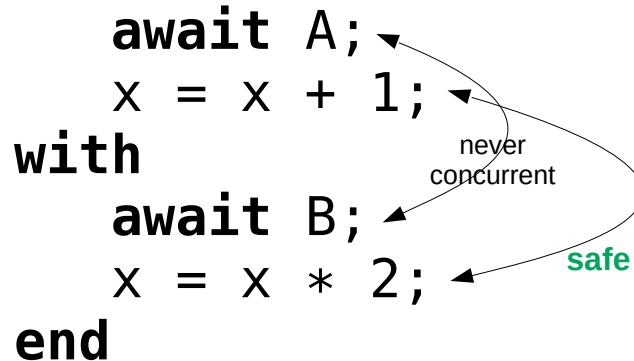
always concurrent

unsafe

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

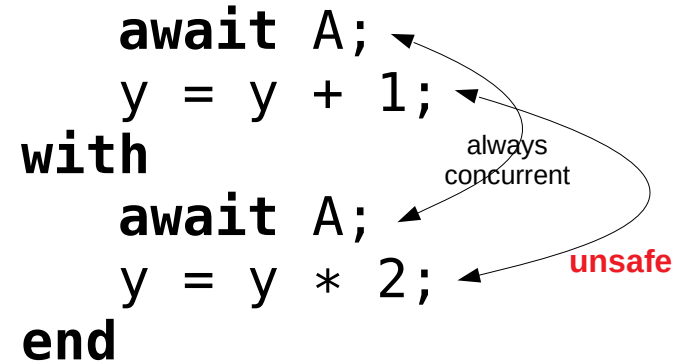
3. Simple Static Checks

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



The diagram shows a curved arrow from the 'await A' block to the 'await B' block, labeled 'never concurrent'. A green label 'safe' is placed at the bottom right of the diagram.

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



The diagram shows a curved arrow from the first 'await A' block to the second 'await A' block, labeled 'always concurrent'. A red label 'unsafe' is placed at the bottom right of the diagram.

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

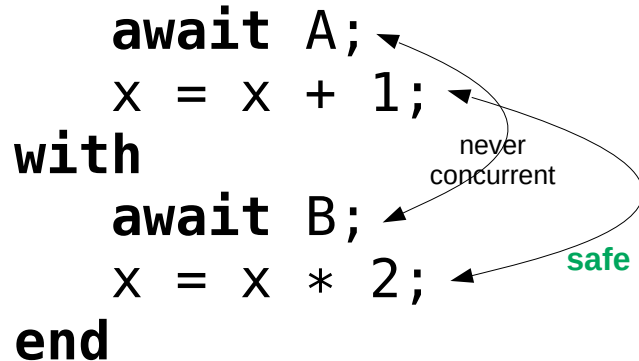


Diagram illustrating a static check for the first code block. A curved arrow labeled "never concurrent" connects the `await A;` statement in the `par/and do` block to the `await B;` statement in the `with` block. The word "safe" is written in green at the bottom right of the diagram.

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

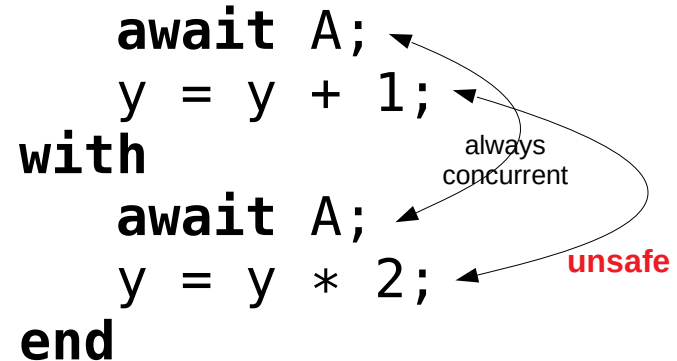


Diagram illustrating a static check for the second code block. A curved arrow labeled "always concurrent" connects the `await A;` statement in the `par/and do` block to the `await A;` statement in the `with` block. The word "unsafe" is written in red at the bottom right of the diagram.

- 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) { <...> }
  void g  (int v) { <...> }
  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) { <...> }
  void g  (int v) { <...> }
  int id  (int v) { <...> }
end

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

- Trackable identifiers ``_`` (*C hat*)

4. Safe Integration with C

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

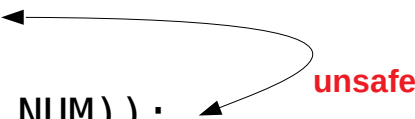
par/and do
  _f();
with
  _g(_id(_NUM));
end
```

- Trackable identifiers ``_`` (*C hat*)
- Assumes all identifiers are conflicting

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
```

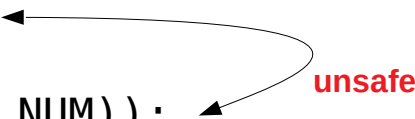


- Trackable identifiers ``_`` (*C hat*)
- Assumes all identifiers are conflicting

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
```

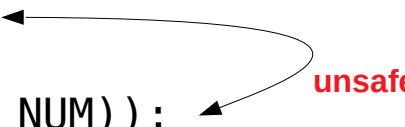


- Trackable identifiers ``_`` (*C hat*)
- Assumes all identifiers are conflicting
- Annotations to eliminate conflicts

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
```



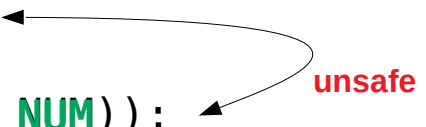
```
native @const _NUM;
```

- 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
```



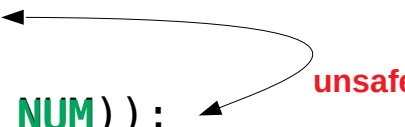
```
native @const _NUM;
```

- 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
```



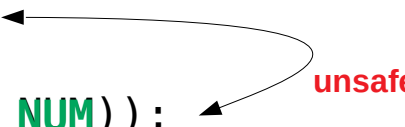
```
native @const _NUM;
native @pure _id();
```

- 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
```



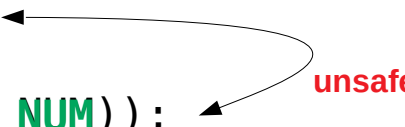
```
native @const _NUM;
native @pure _id();
```

- 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
```



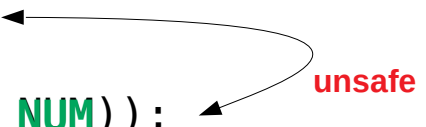
```
native @const _NUM;
native @pure _id();
native @safe _f() with _g();
```

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

4. Safe Integration with C

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

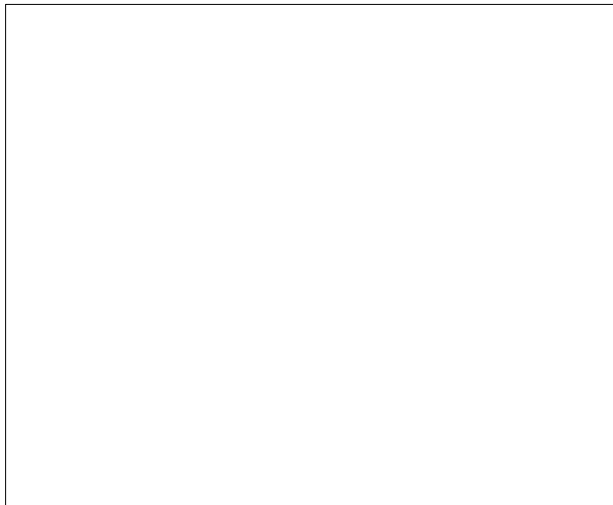
par/and do
  _f();
with
  _g(_id(_NUM));
end
```



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

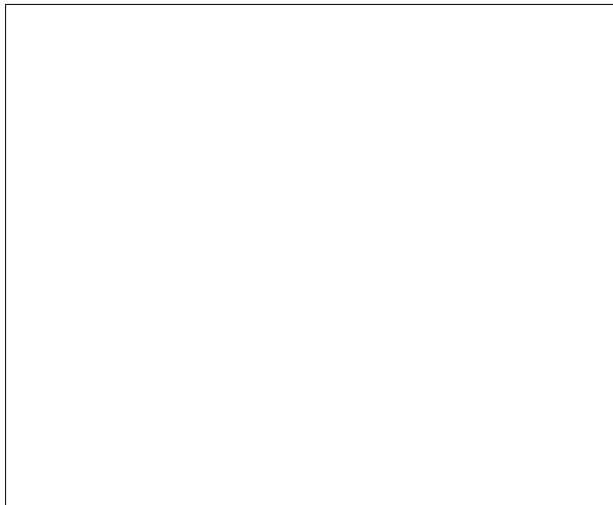
- Trackable identifiers ``_`` (*C hat*)
- Assumes all identifiers are conflicting
- Annotations to eliminate conflicts

4. Safe Integration with C



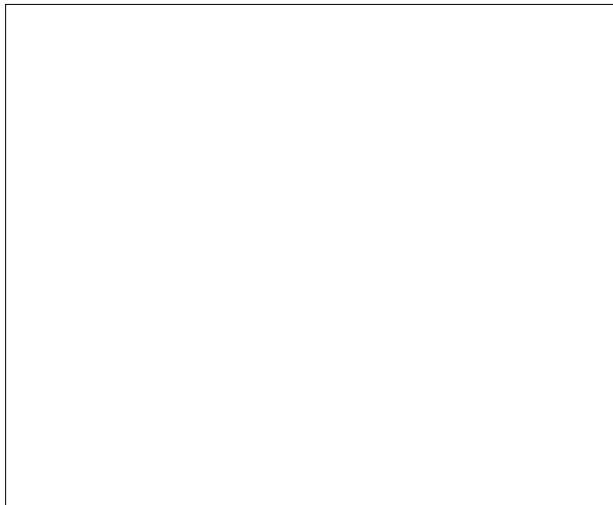
4. Safe Integration with C

- Abortion of trails dealing with resources is unsafe



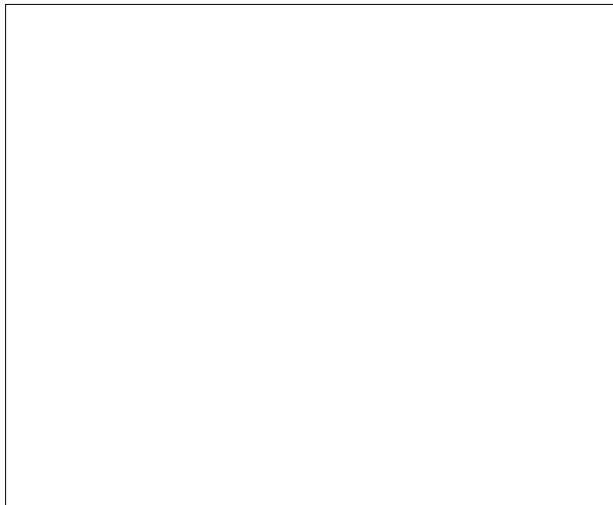
4. Safe Integration with C

- Abortion of trails dealing with resources is unsafe



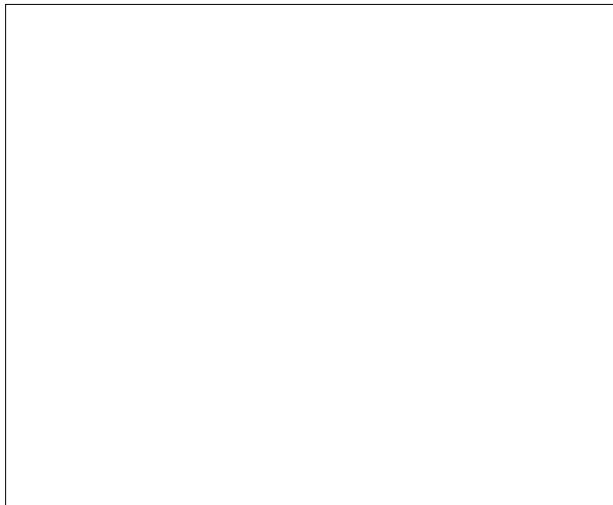
4. Safe Integration with C

- Abortion of trails dealing with resources is unsafe



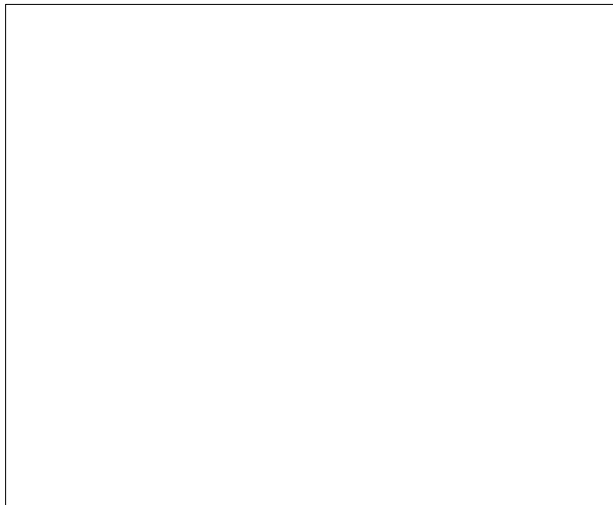
4. Safe Integration with C

- Abortion of trails dealing with resources is unsafe



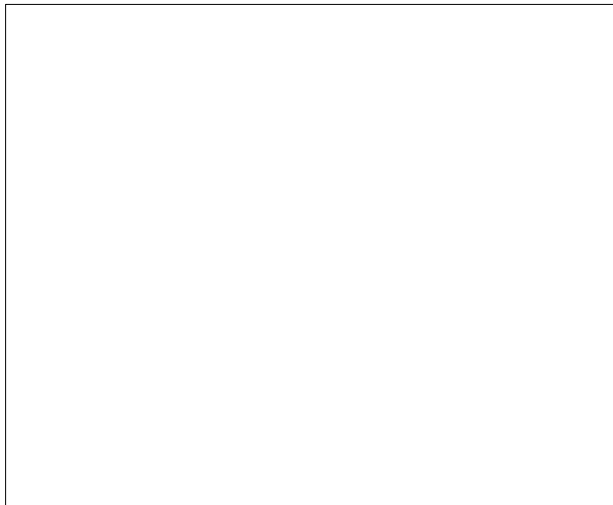
4. Safe Integration with C

- Abortion of trails dealing with resources is unsafe



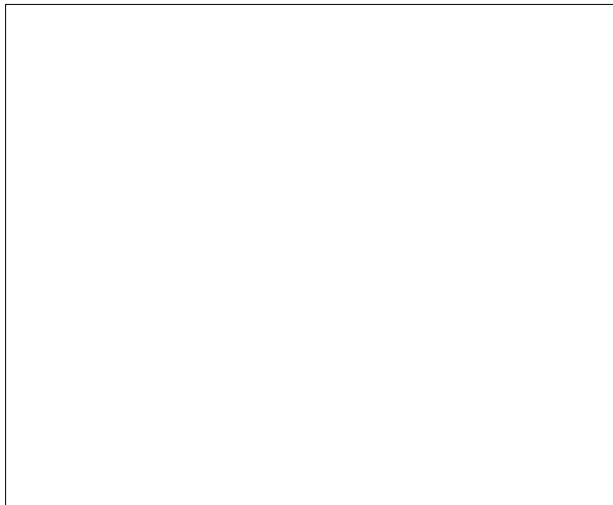
4. Safe Integration with C

- Abortion of trails dealing with resources is unsafe



4. Safe Integration with C

- Abortion of trails dealing with resources is unsafe



4. Safe Integration with C

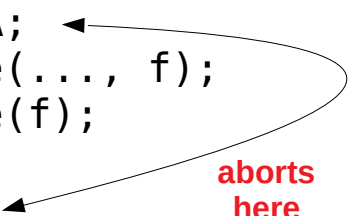
- Abortion of trails dealing with resources is unsafe

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


4. Safe Integration with C

- Abortion of trails dealing with resources is unsafe

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

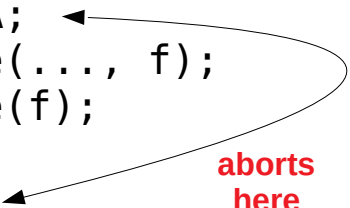


aborts
here

4. Safe Integration with C

- Abortion of trails dealing with resources is unsafe
- Finalization mechanism

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

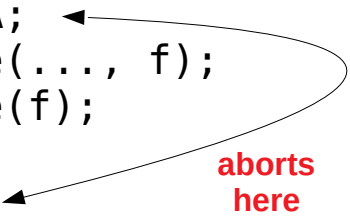


aborts
here

4. Safe Integration with C

- Abortion of trails dealing with resources is unsafe
- Finalization mechanism
 - Pointer assignment must be finalized

```
par/or do
  var _FILE* f;
  f = _fopen(...);
  _fwrite(..., f);
  await A; ←
  _fwrite(..., f);
  _fclose(f);
with
  <...> ← aborts here
end
```



4. Safe Integration with C

- Abortion of trails dealing with resources is unsafe
- Finalization mechanism
 - Pointer assignment must be finalized

```
par/or do
  var _FILE* f;
  f = _fopen(...);
  _fwrite(..., f);
  await A; ←
  _fwrite(..., f);
  _fclose(f);
with
  <...> ← aborts here
end
```

4. Safe Integration with C

- Abortion of trails dealing with resources is unsafe
- Finalization mechanism
 - Pointer assignment must be finalized

```
par/or do
  var _FILE* f;
  f = _fopen(...);
  fwrite(..., f);
  line 2 : requires 'finalize'
  _fwrite(..., T);
  _fclose(f);
with
  <...>
end
```

aborts here

4. Safe Integration with C

- Abortion of trails dealing with resources is unsafe
- Finalization mechanism
 - Pointer assignment must be finalized

```
par/or do
  var _FILE* f;
  f = _fopen(...);
  fwrite(..., f);
  line 2 : requires 'finalize'
  _fwrite(..., f);
  _fclose(f);
with
  <...>
end
```

aborts here

```
par/or do
  var _FILE* f;
```

4. Safe Integration with C

- Abortion of trails dealing with resources is unsafe
- Finalization mechanism
 - Pointer assignment must be finalized

```
par/or do
  var _FILE* f;
  f = _fopen(...);
  fwrite(..., f);
  _fwrite(..., f);
  _fclose(f);
with
  <...>
end
```

line 2 : requires 'finalize'

aborts here

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

4. Safe Integration with C

- Abortion of trails dealing with resources is unsafe
- Finalization mechanism
 - Pointer assignment must be finalized
 - External resource: pointer from C to Céu (*memory leak*)

```
par/or do
  var _FILE* f;
  f = _fopen(...);
  fwrite(..., f);
  line 2 : requires 'finalize'
  _fwrite(..., f);
  _fclose(f);
with
  <...>
end
```

aborts here

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


4. Safe Integration with C

- Abortion of trails dealing with resources is unsafe
- Finalization mechanism
 - Pointer assignment must be finalized
 - External resource: pointer from C to Céu (*memory leak*)
 - Local resource: pointer from Céu to C (*dangling pointer*)

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par/or do
  var _FILE* f;
  f = _fopen(...);
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  _fwrite(..., f);
  _fclose(f);
with
  <...>
end
```

line 2 : requires 'finalize'

aborts here

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

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  <...>
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```

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

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with
  <...>
end
```

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  finalize
    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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aborts here

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

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

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

```
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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- Timers, watchdogs, sampling all very common

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

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- Timers, watchdogs, sampling all very common
 1. Dedicated syntax
 2. Delta compensation (system vs program mismatch)

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

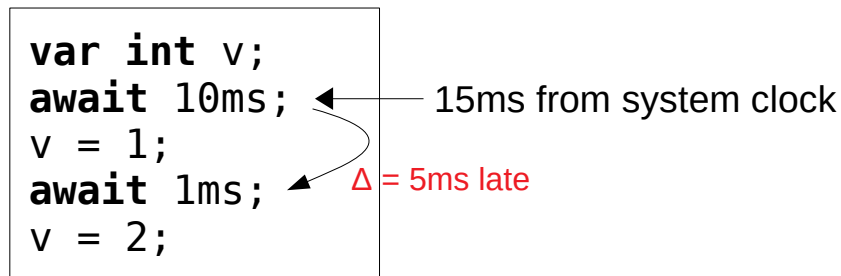
5. First-Class Timers

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

```
var int v;  
await 10ms; ← 15ms from system clock  
v = 1;  
await 1ms;  
v = 2;
```

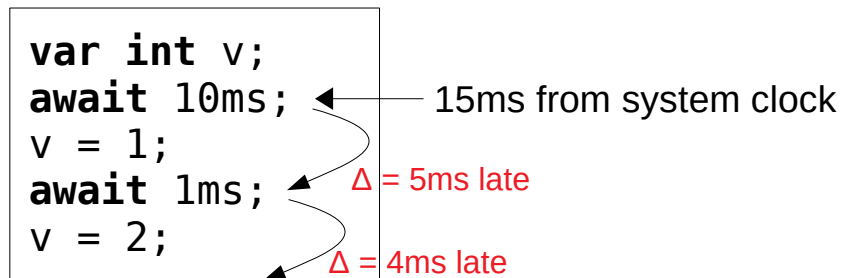
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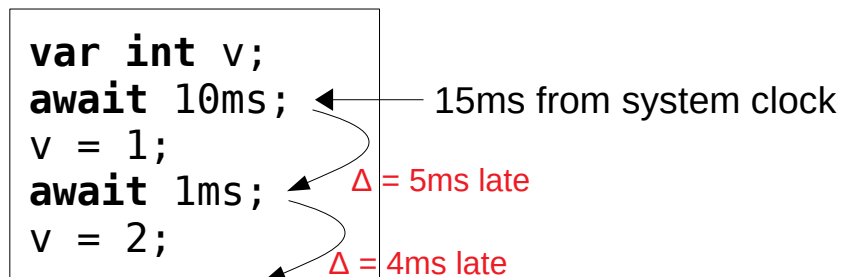
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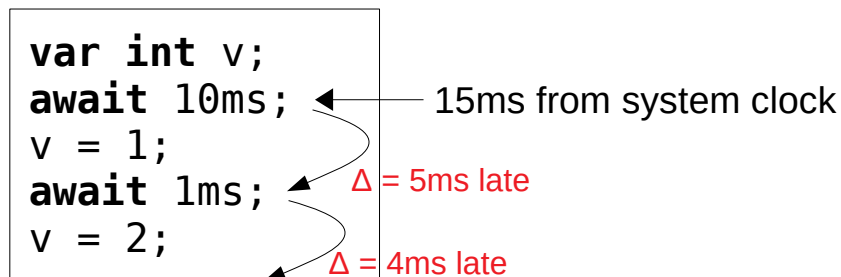
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```
var int v;  
par/or do  
    await 10ms;  
    await 1ms;  
    v = 1;  
with  
    await 12ms;  
    v = 2;  
end
```


5. First-Class Timers

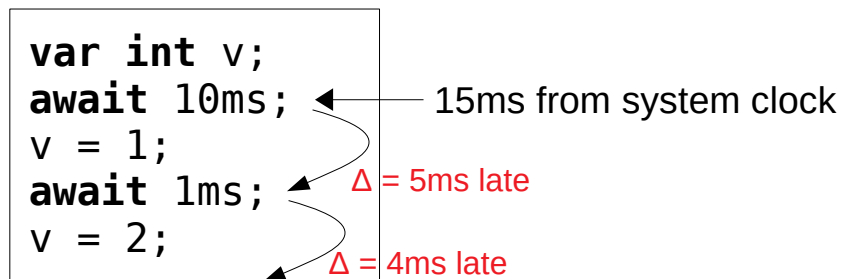
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    await 1ms;  
    ① v = 1;  
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    await 12ms;  
    v = 2;  
end
```

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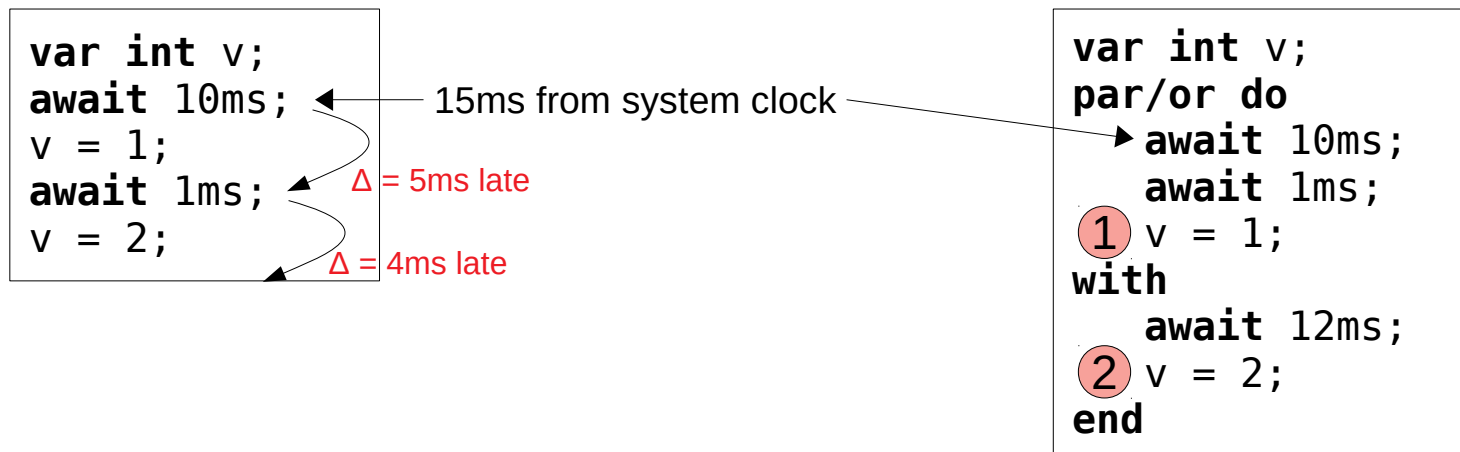
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with  
    await 12ms;  
    2 v = 2;  
end
```

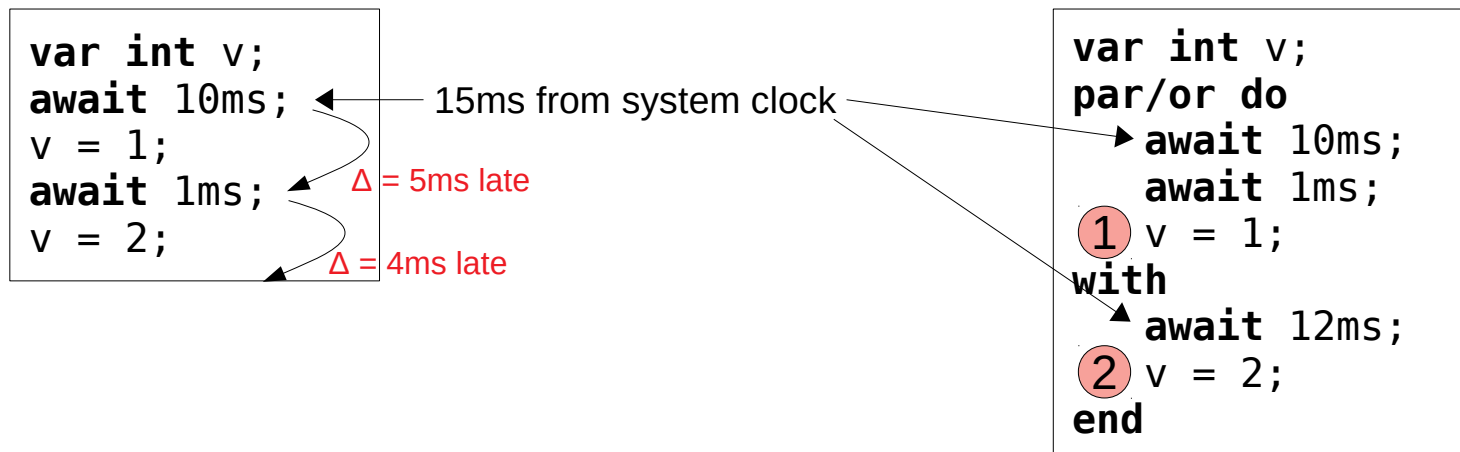
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Applications / Other Work

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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



1. External Events

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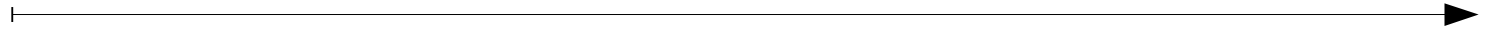
Esterel
(fixed tick)

Céu
(unique input)

1. External Events

Esterel
(fixed tick)

Timeline
(discrete)



Céu
(unique input)

Timeline
(discrete)

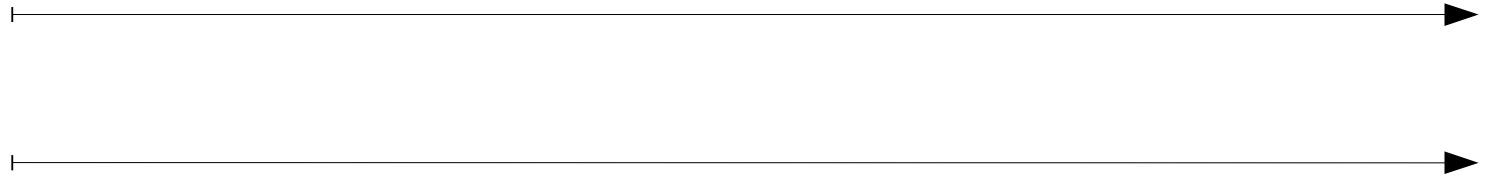


1. External Events

Esterel
(fixed tick)

Timeline
(discrete)

CPU reaction



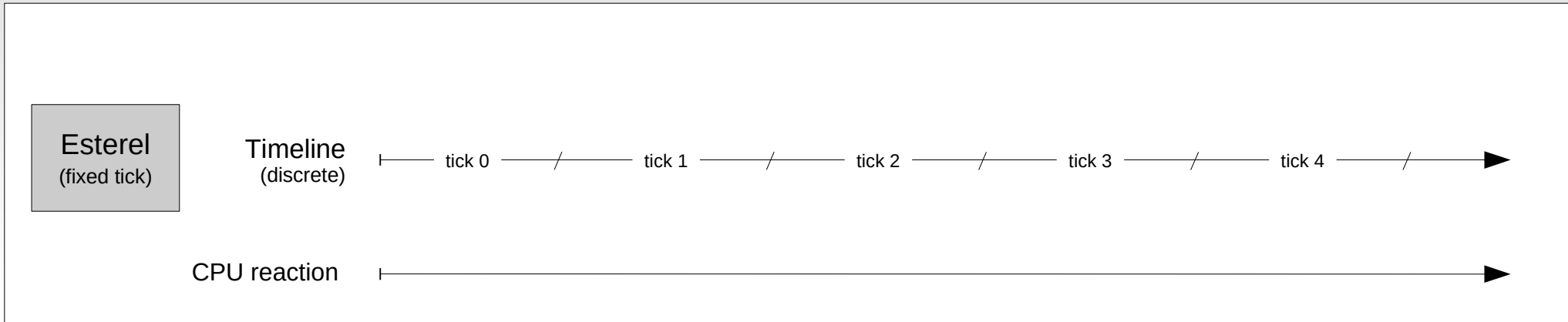
Céu
(unique input)

Timeline
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CPU reaction

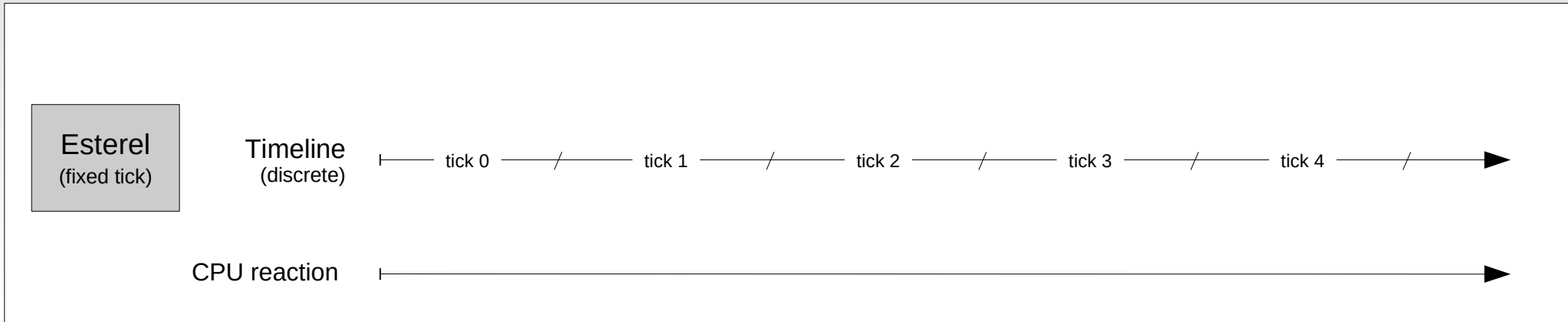


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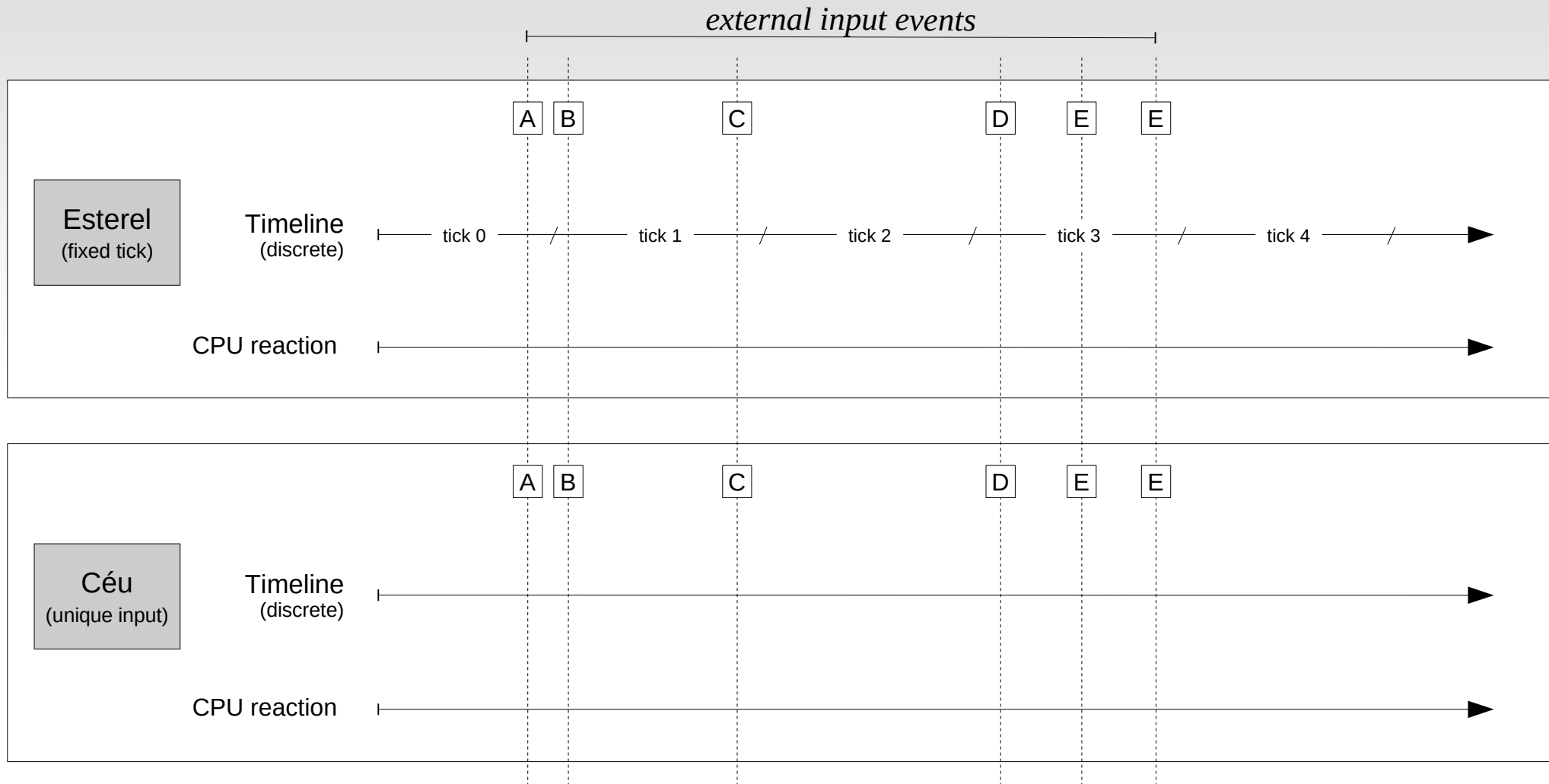


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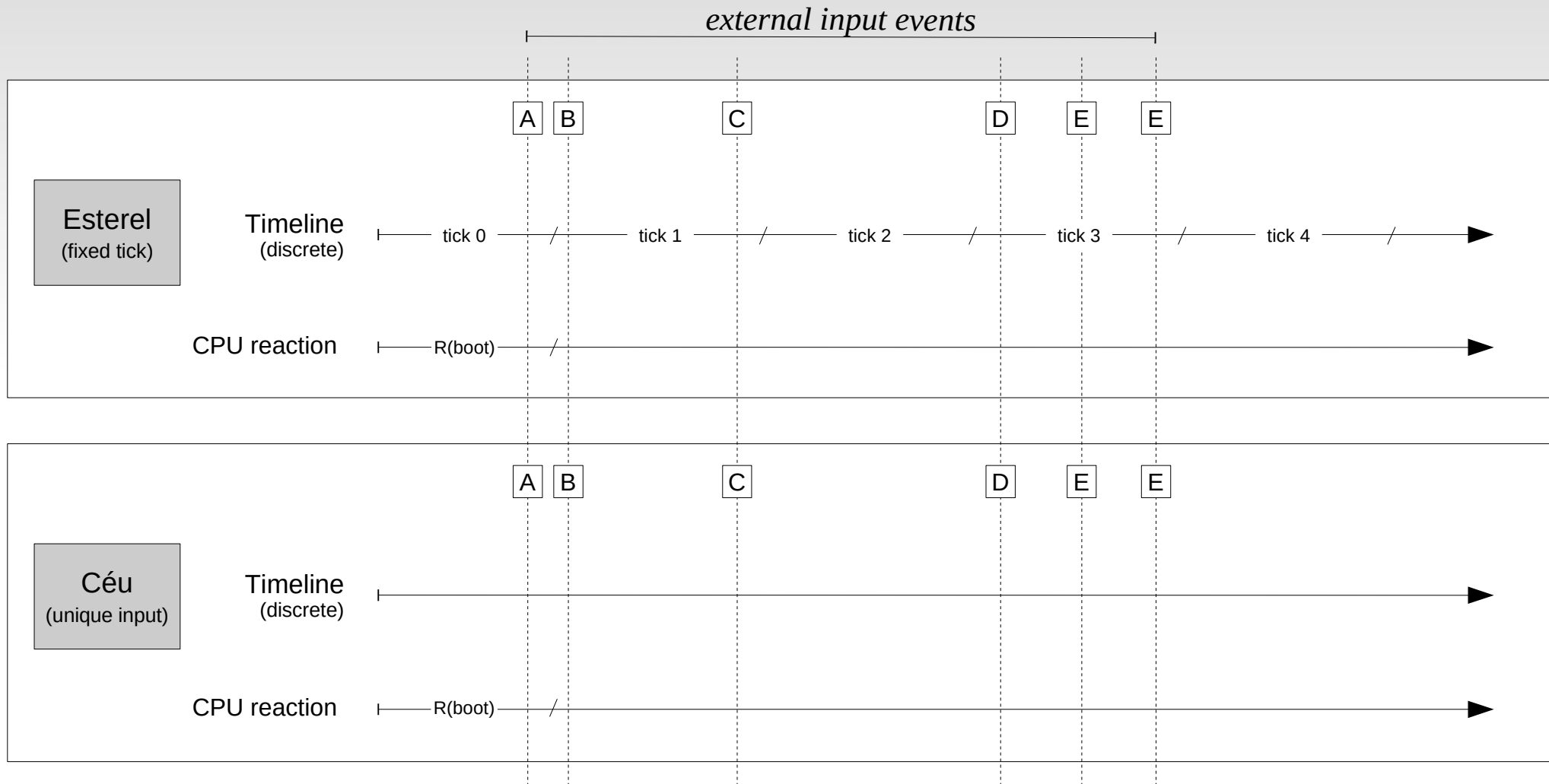
external input events



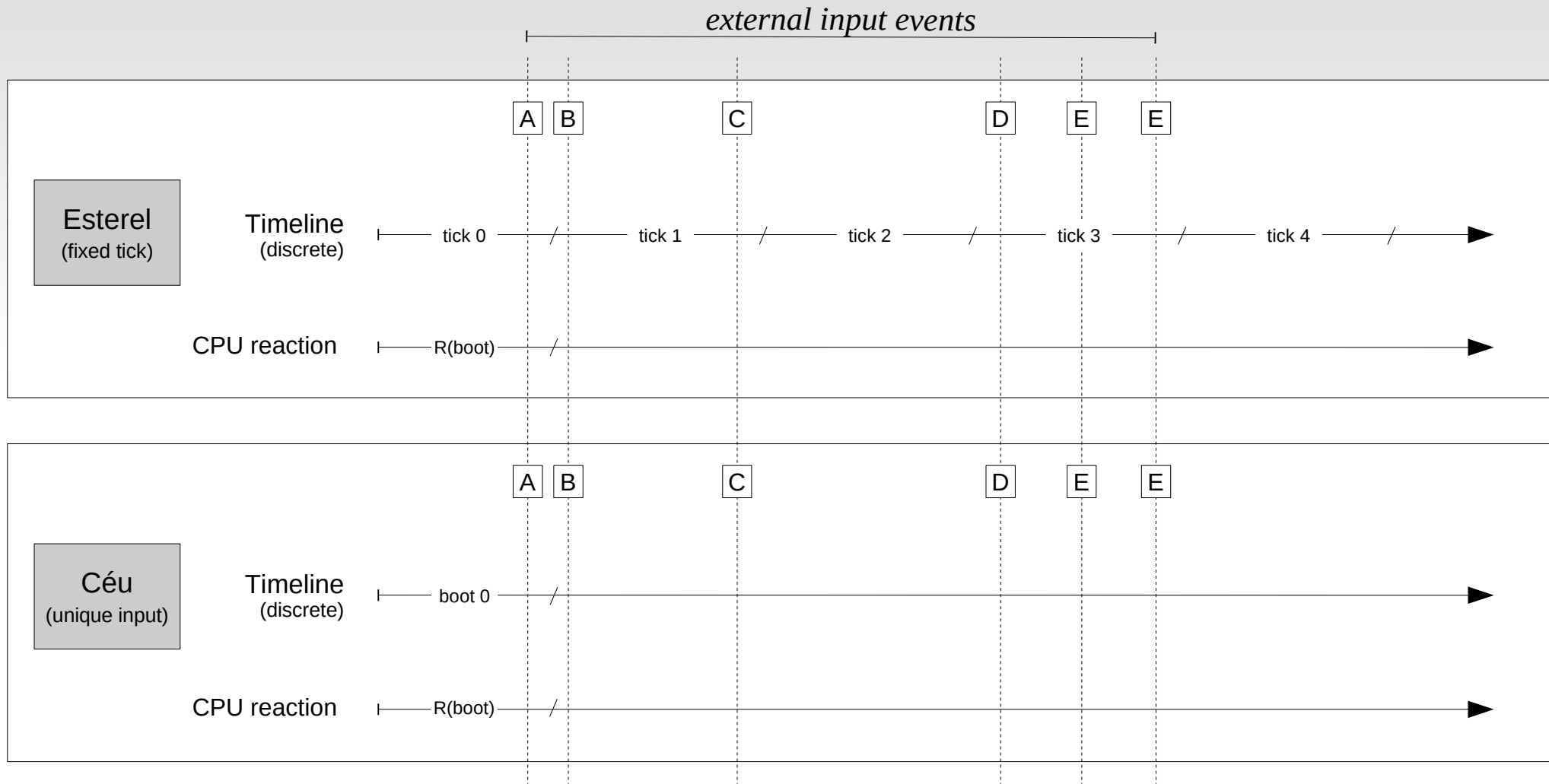
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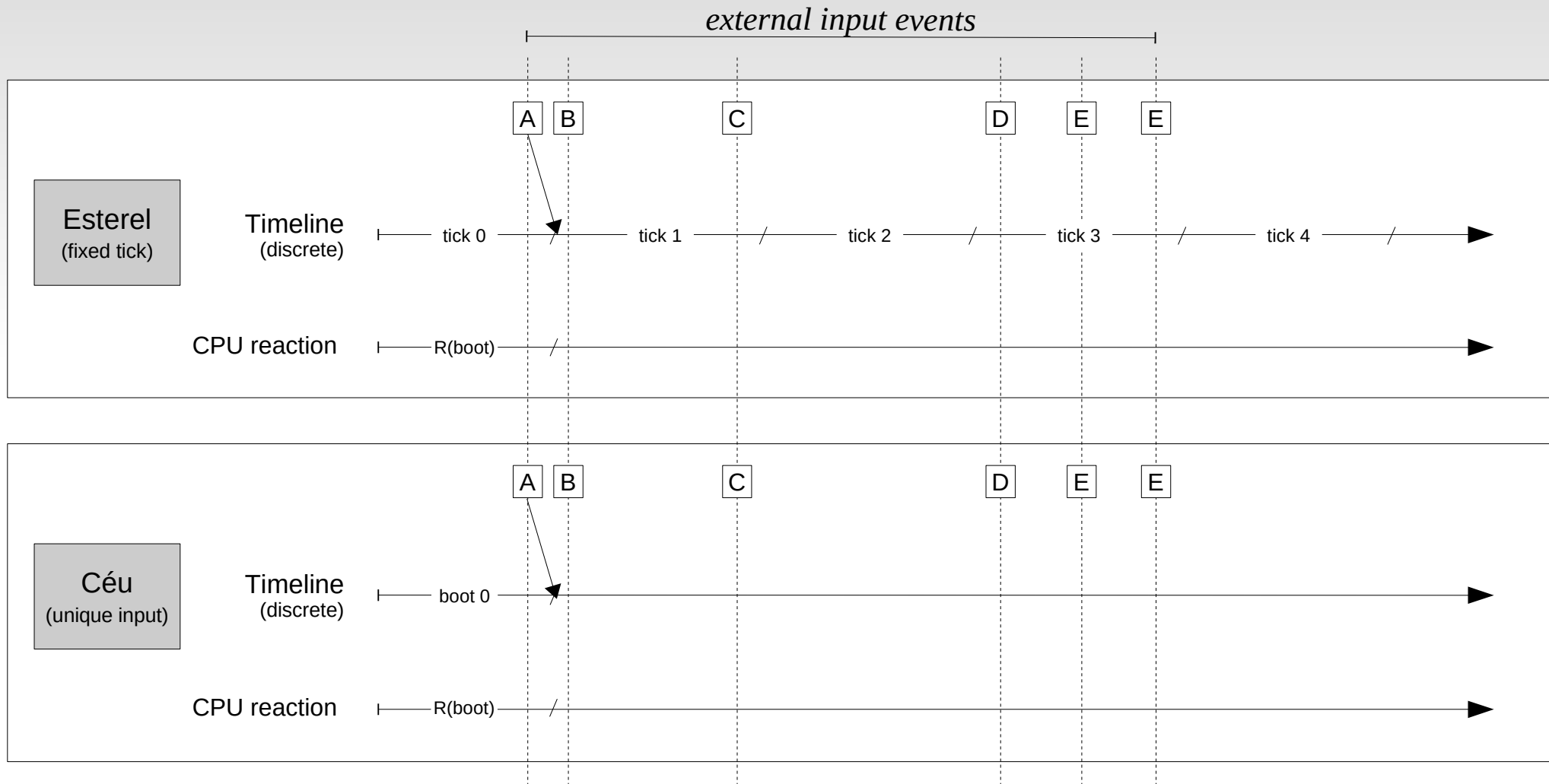
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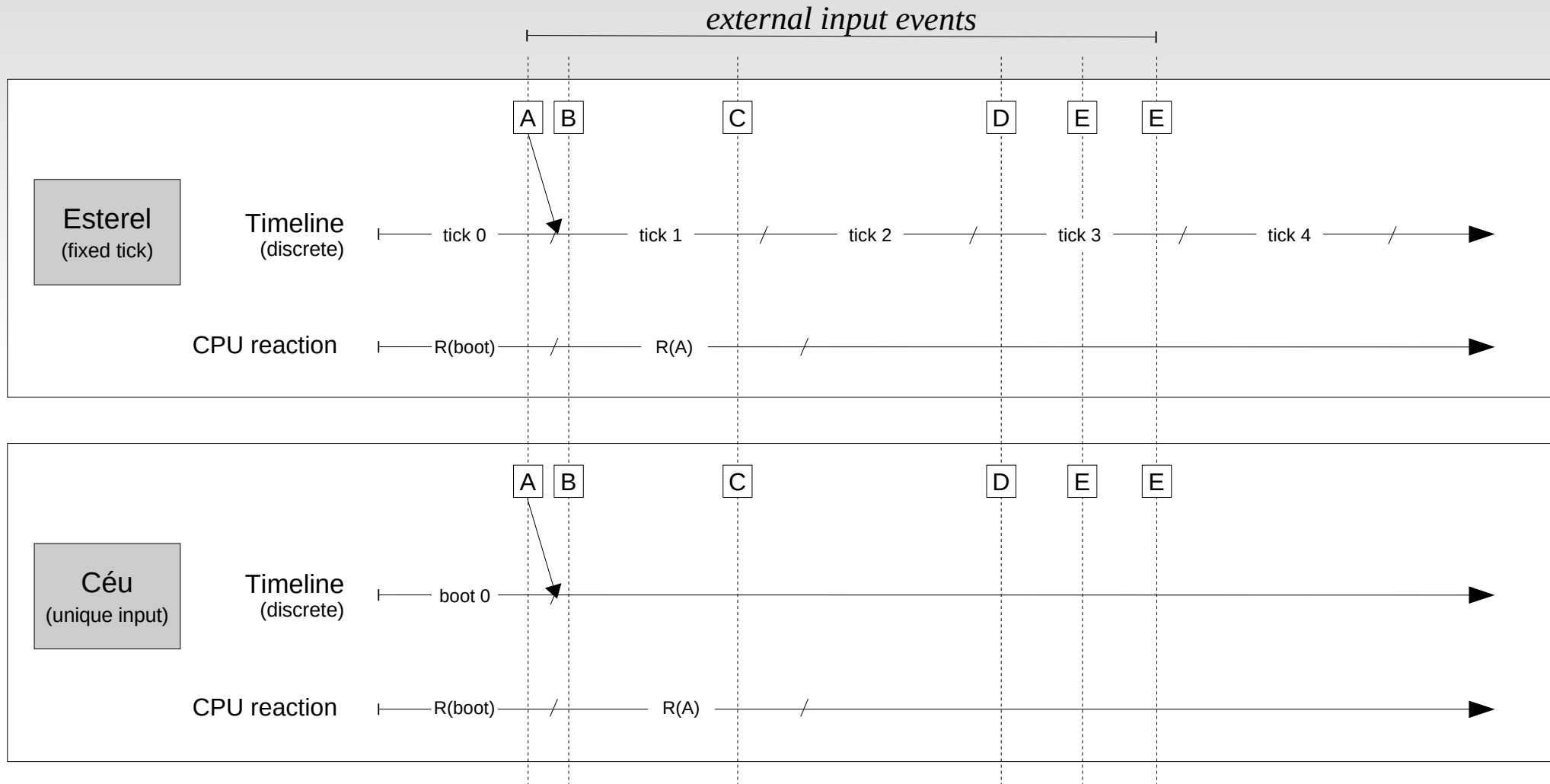
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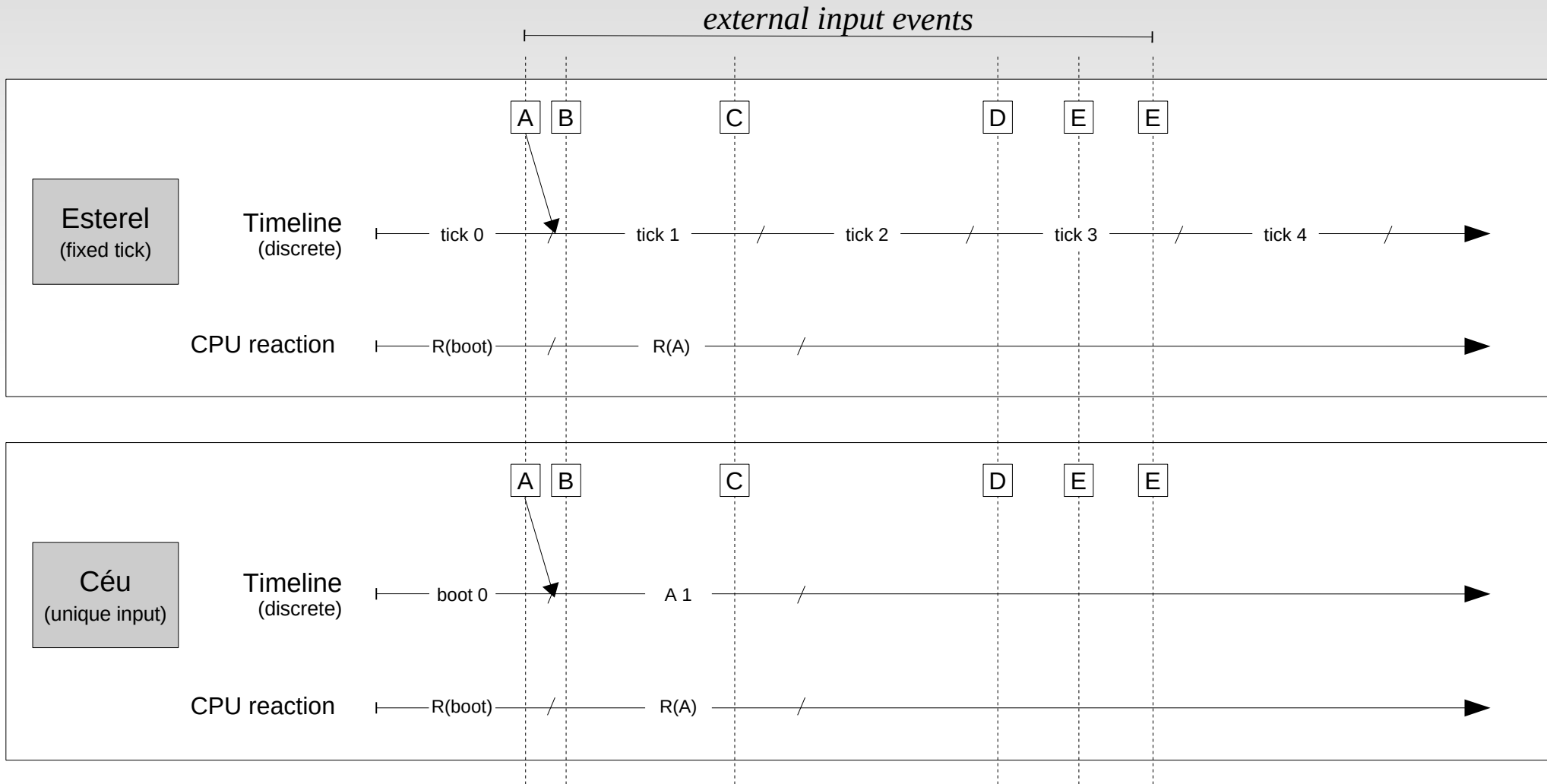
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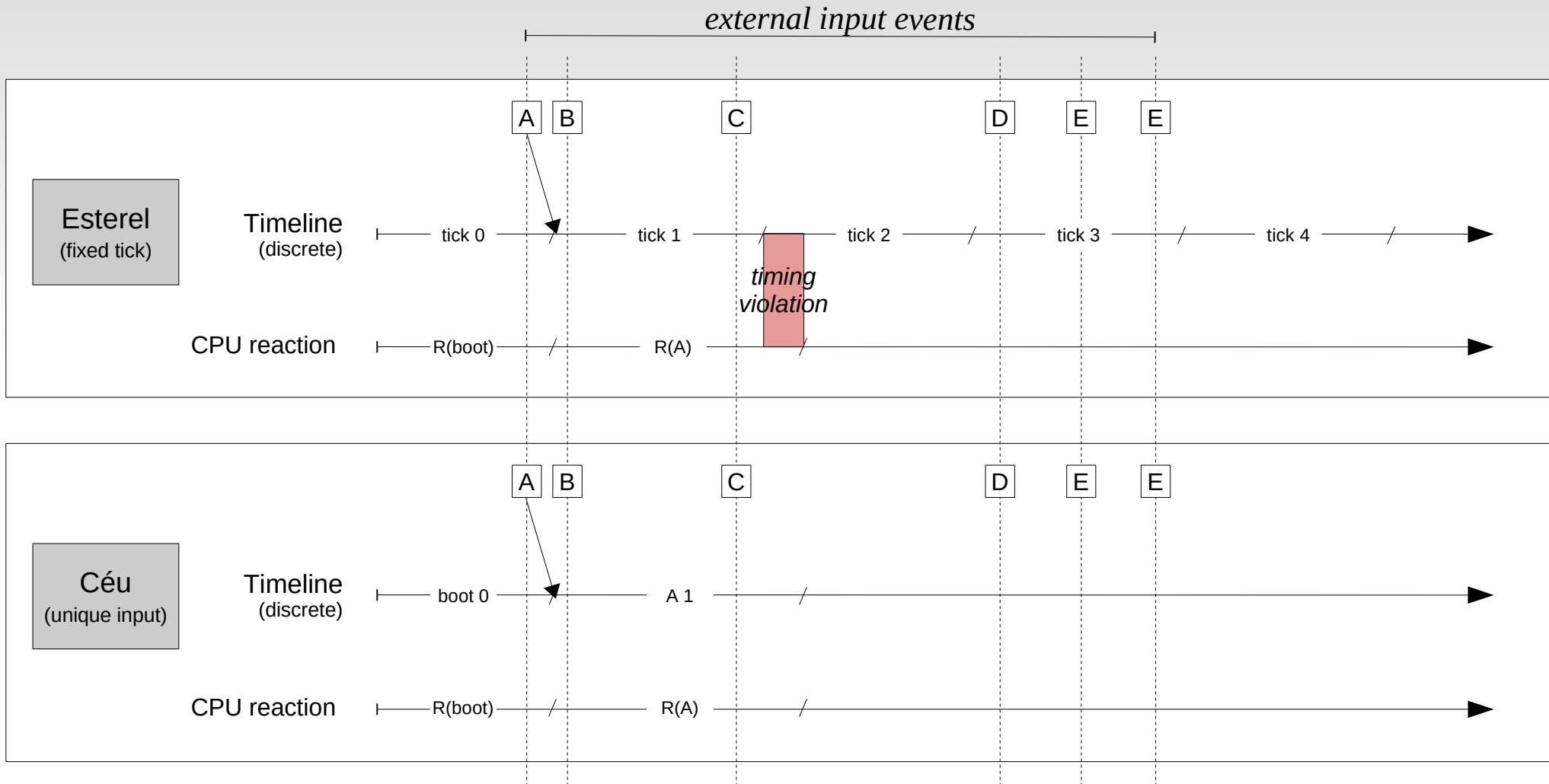
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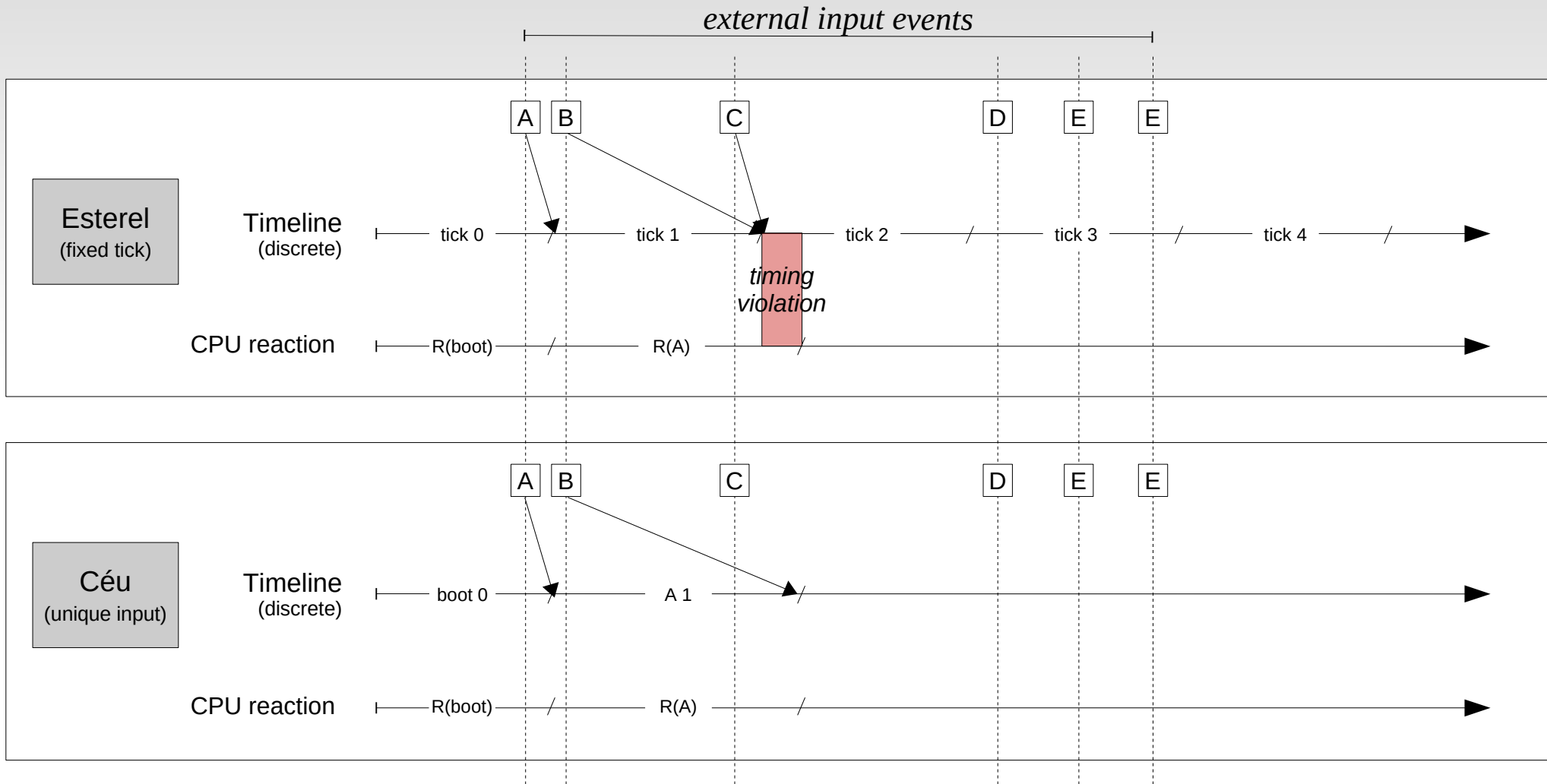
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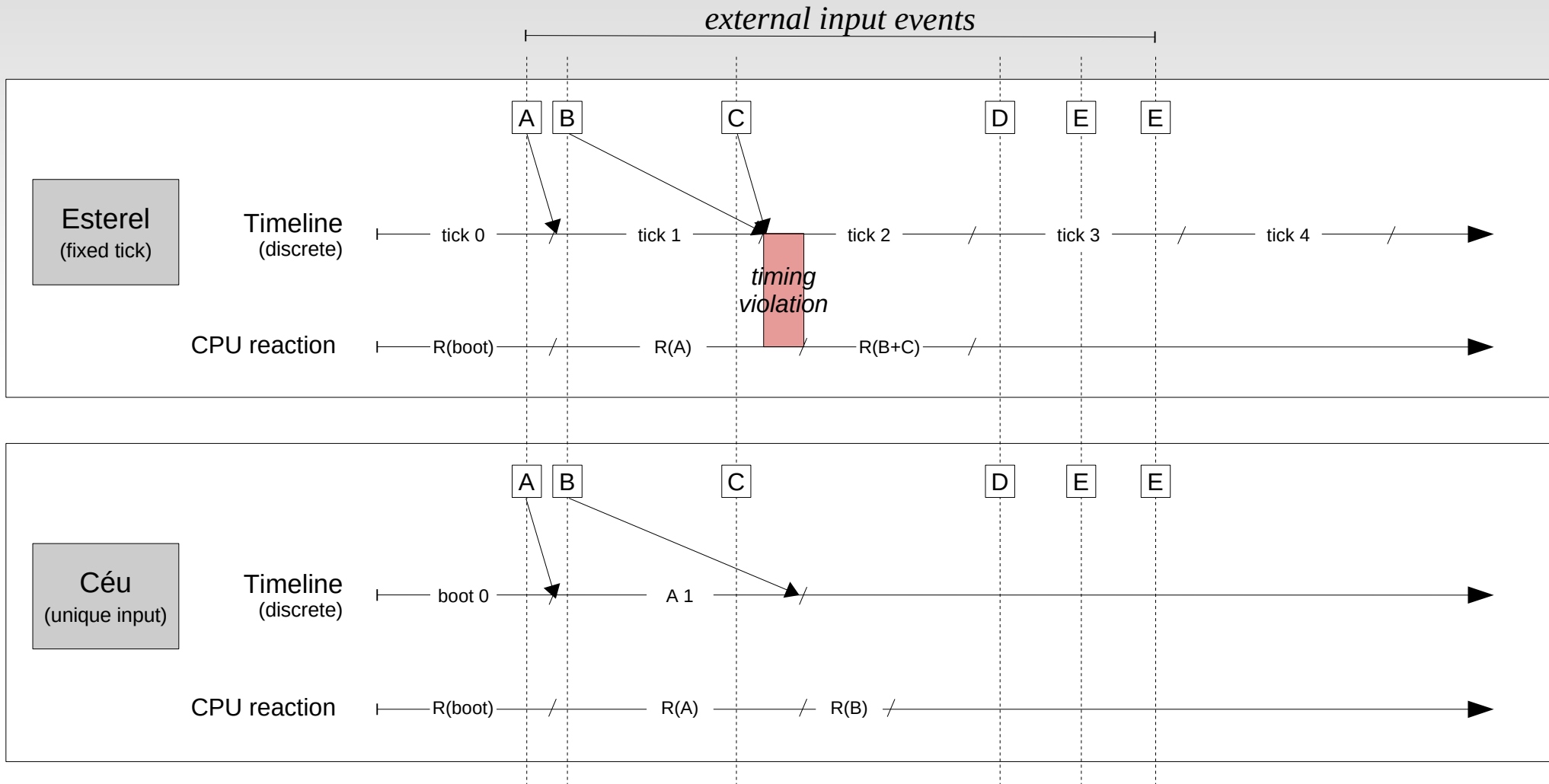
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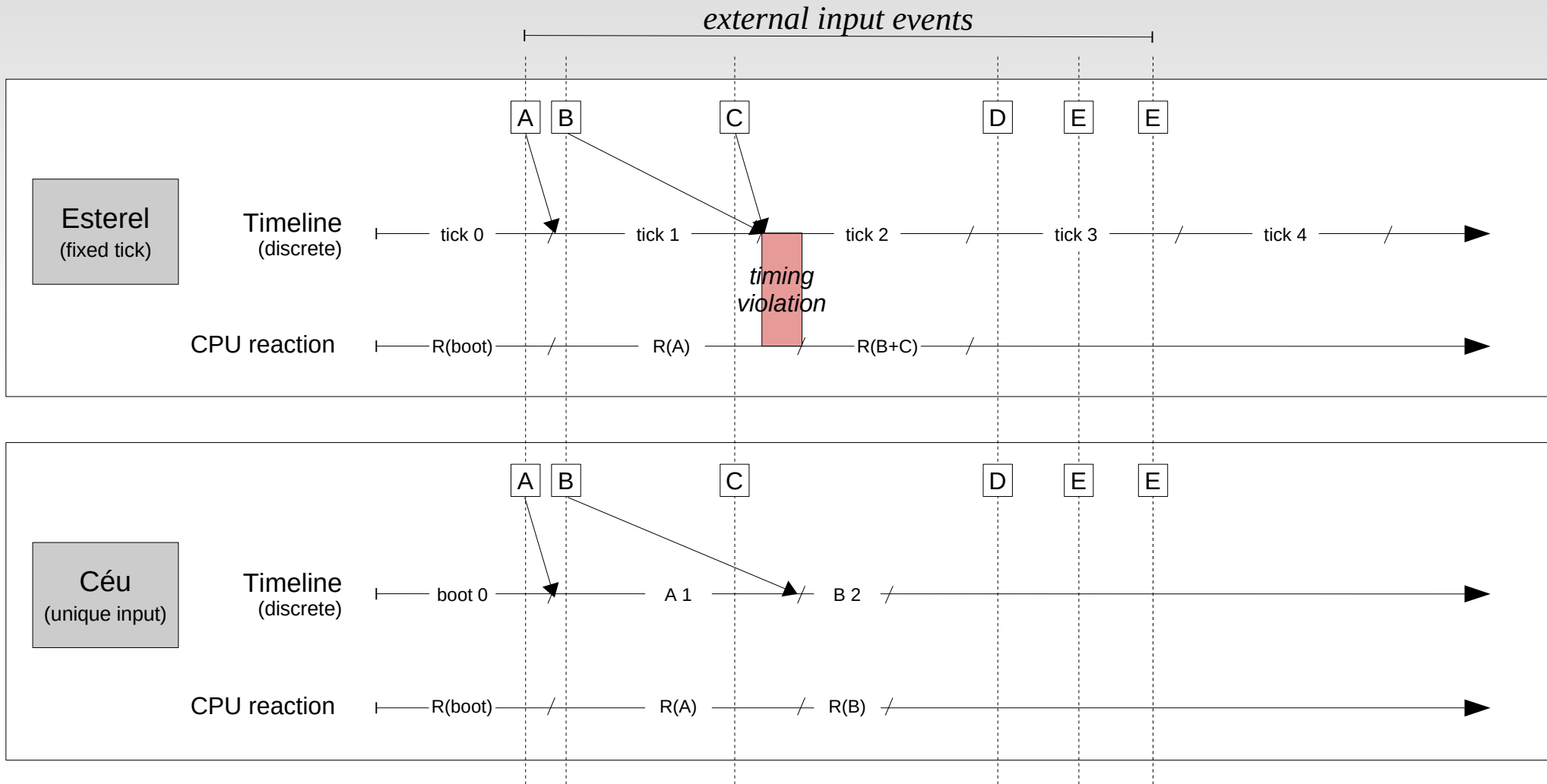
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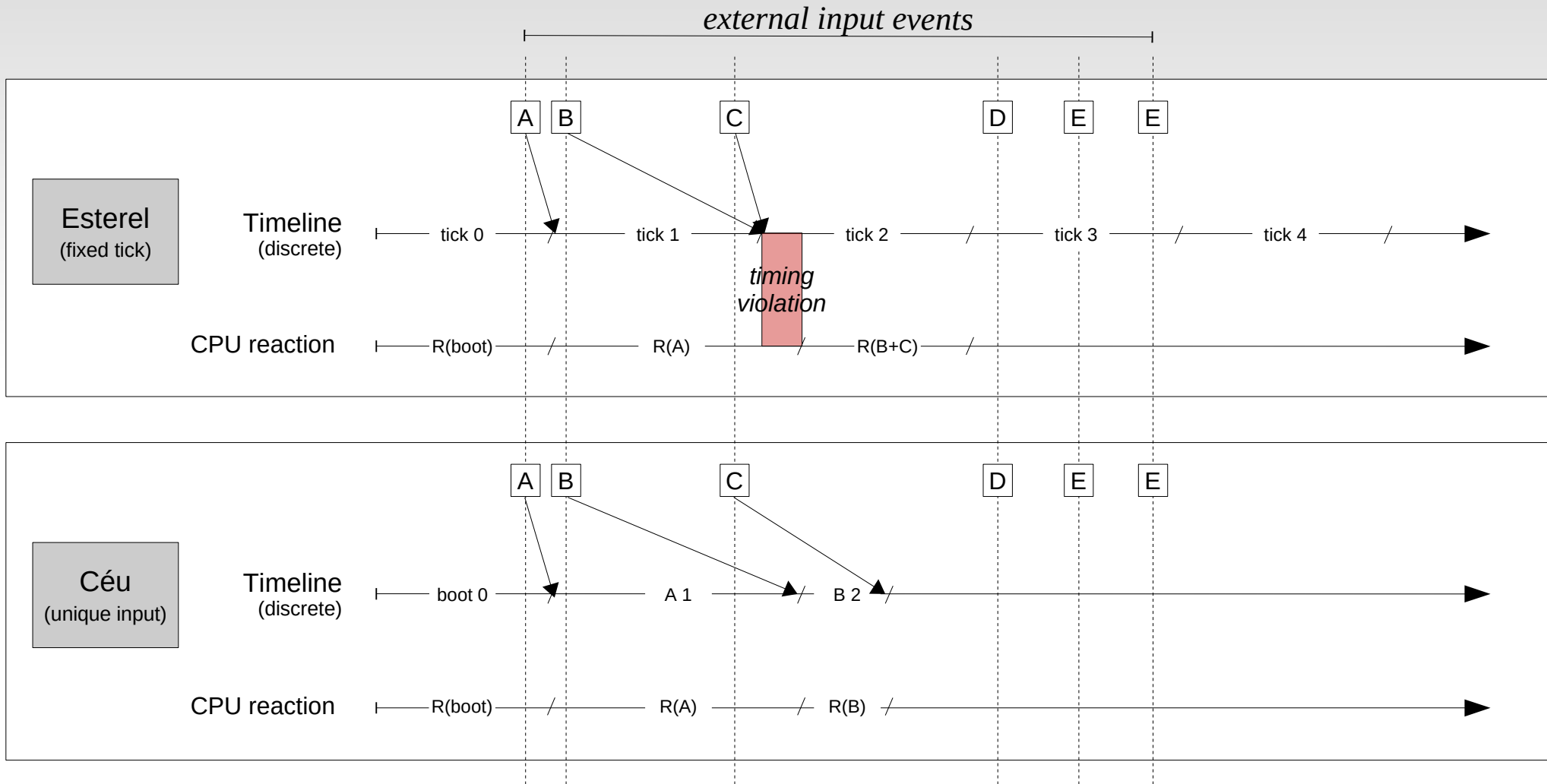
1. External Events



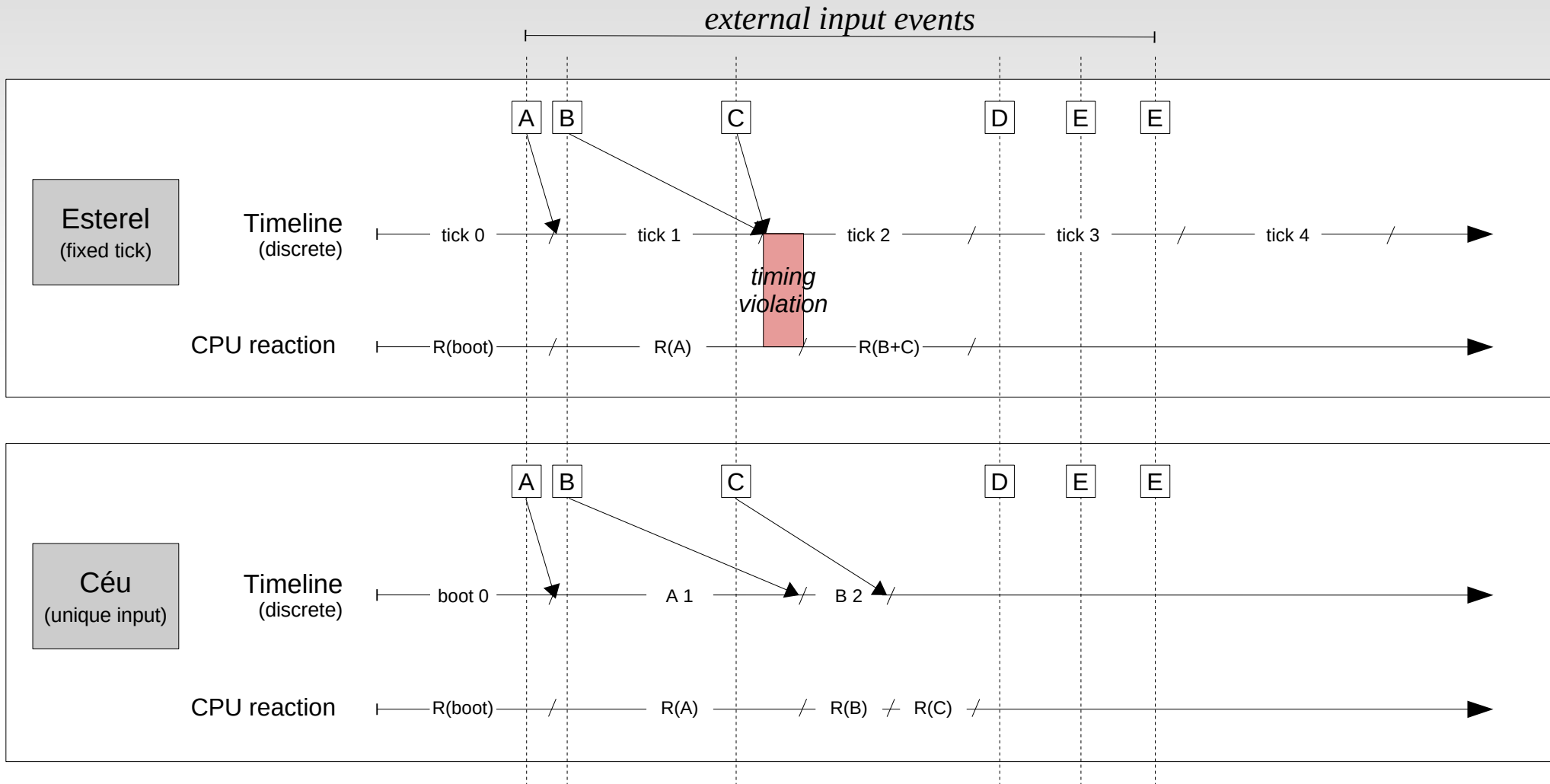
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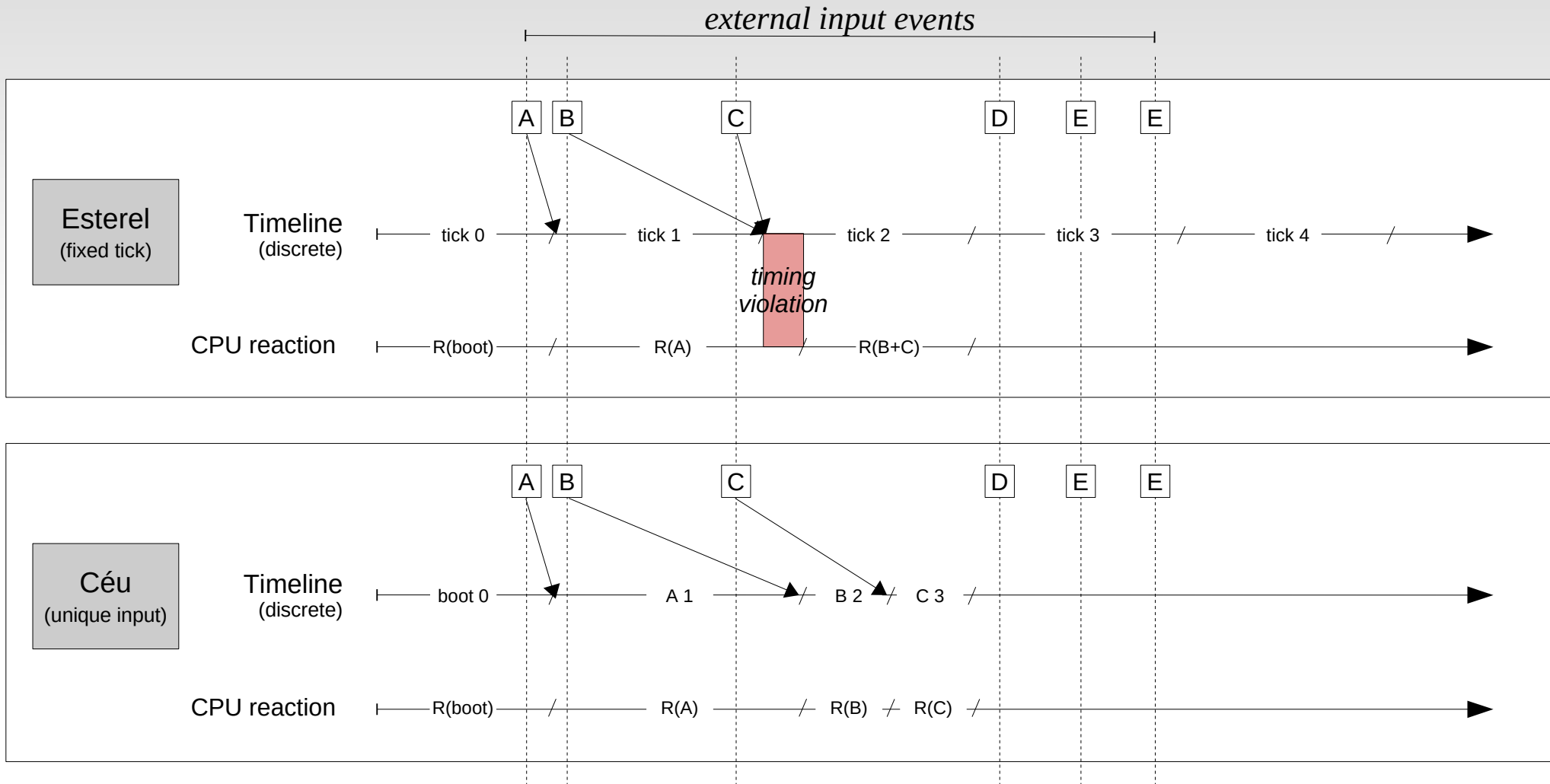
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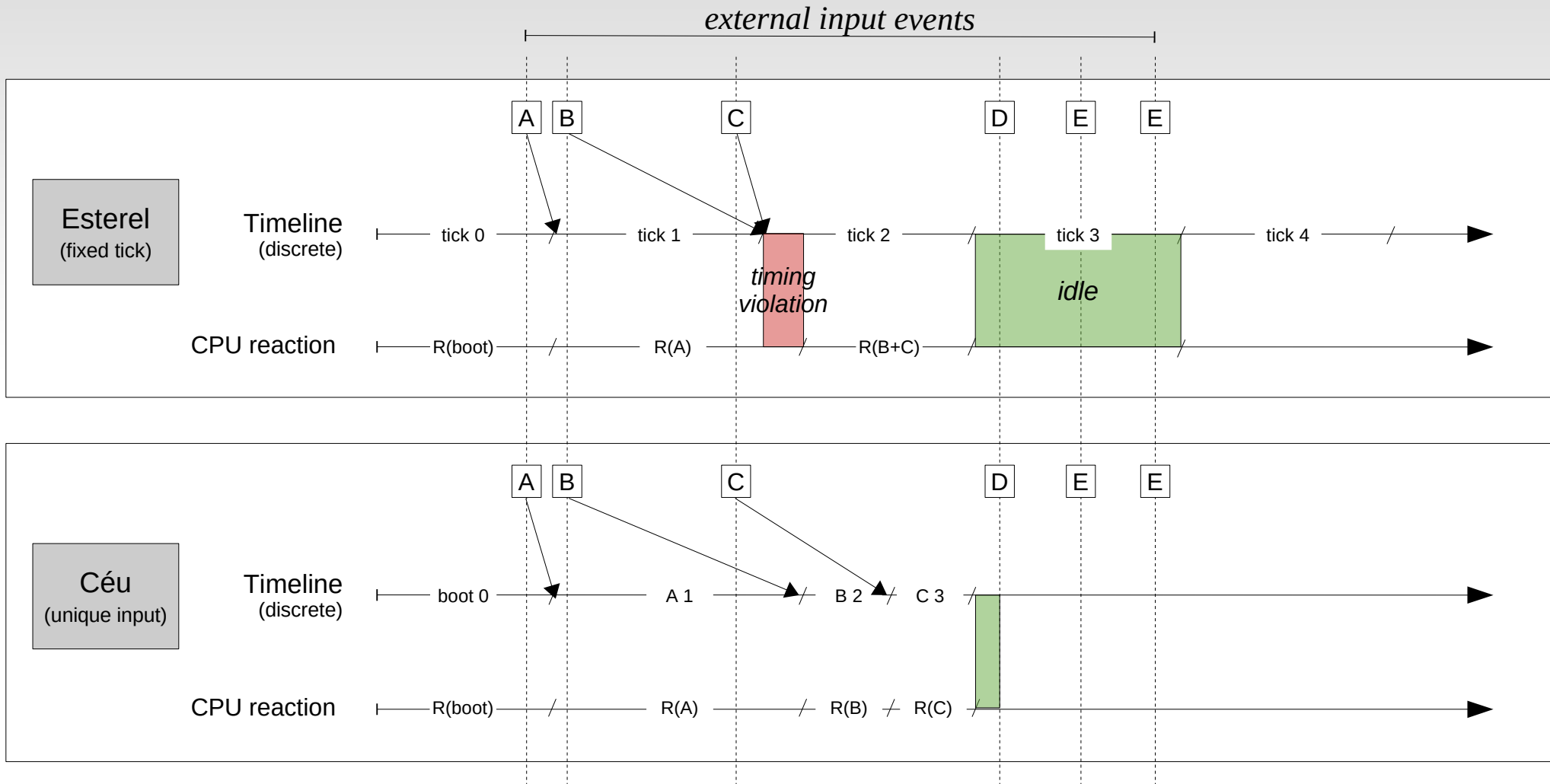
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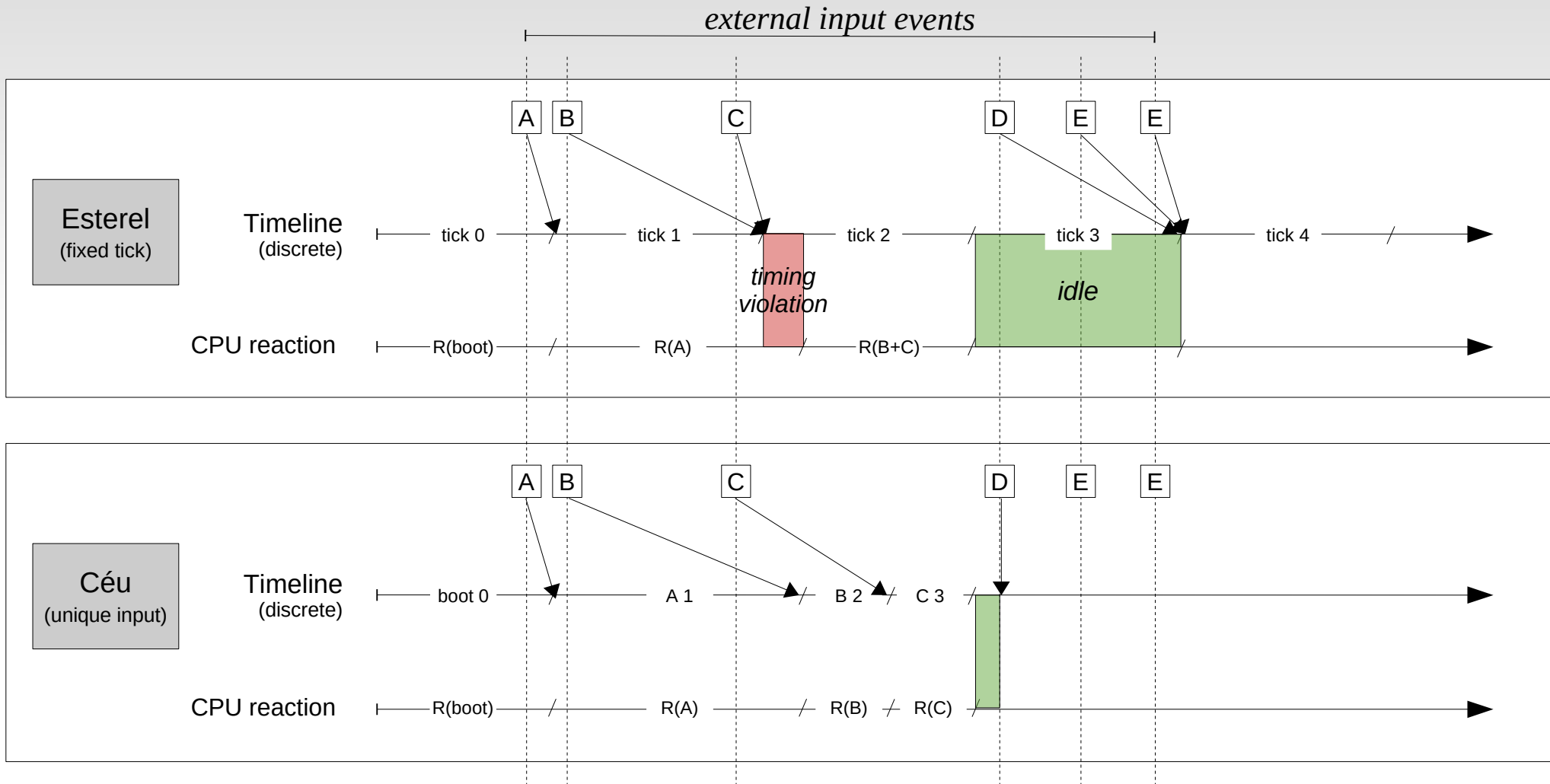
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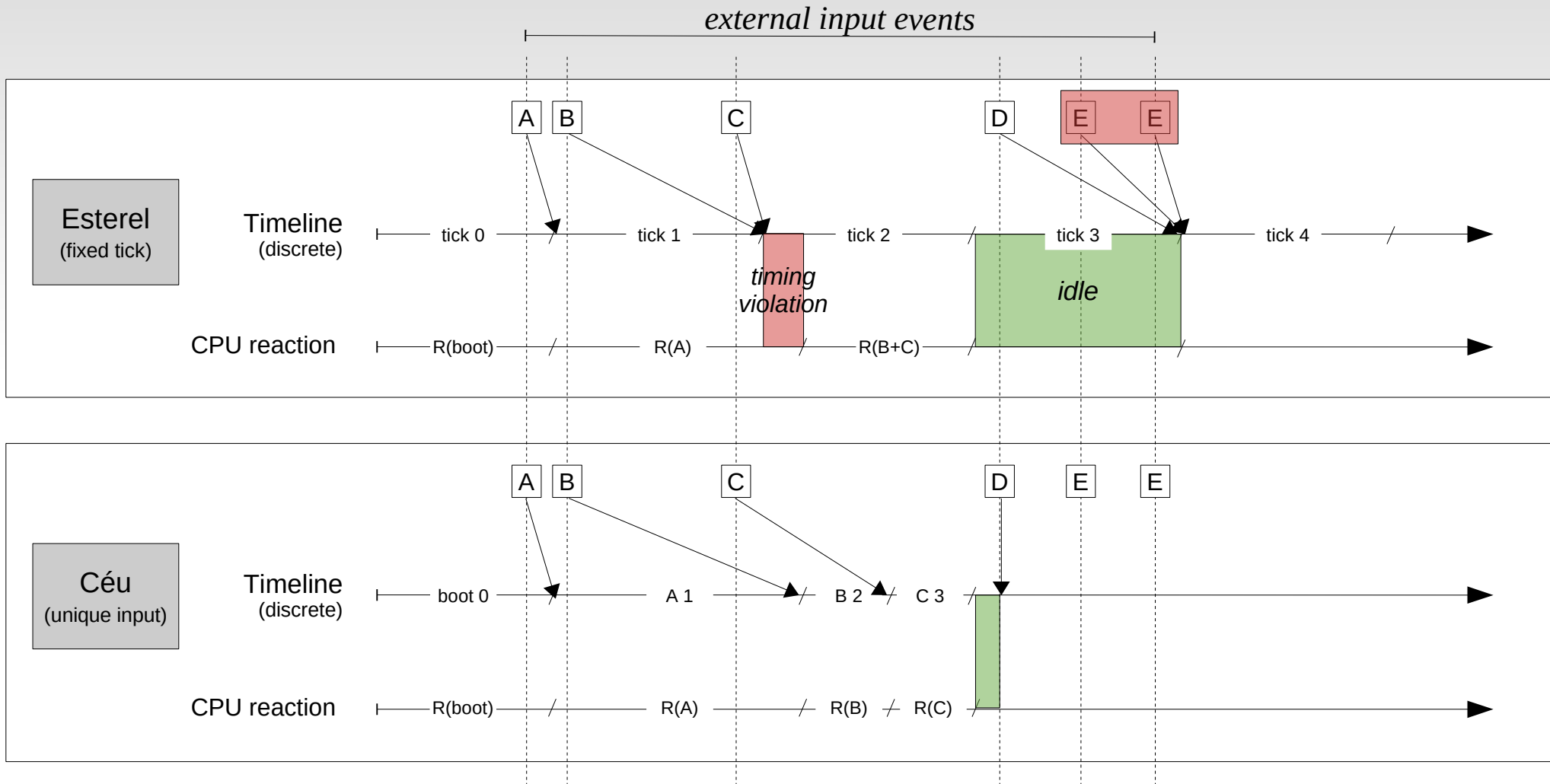
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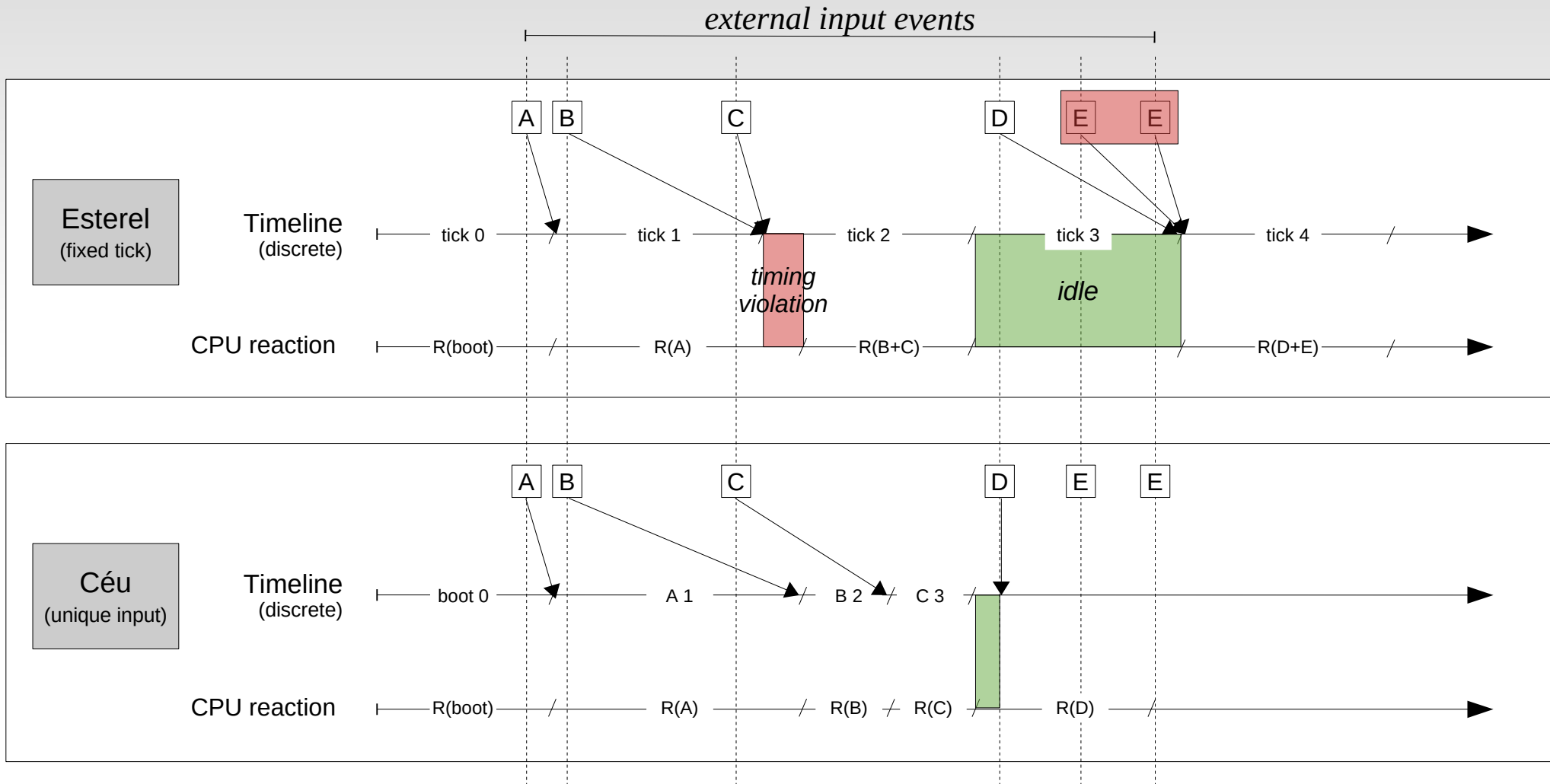
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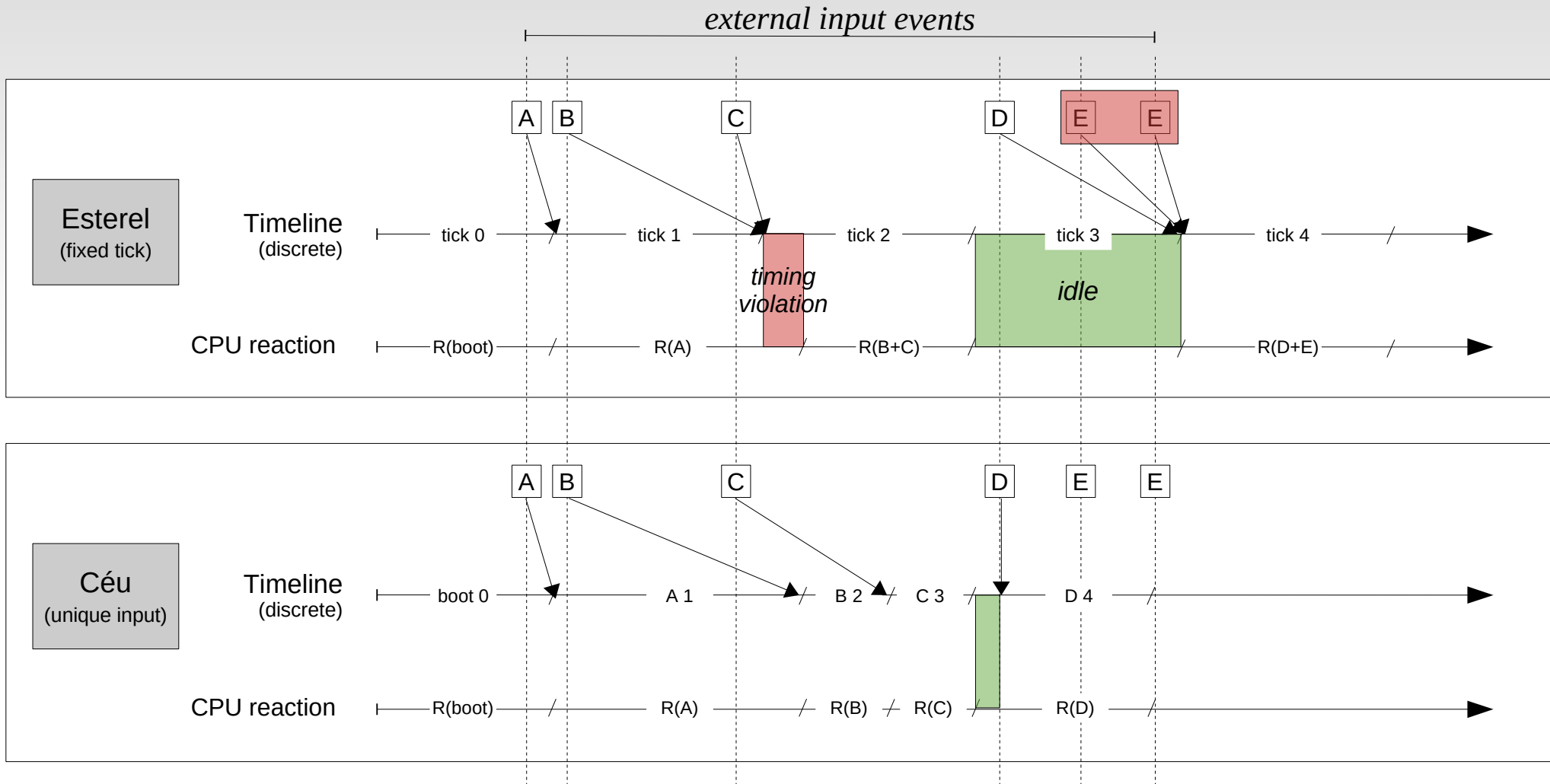
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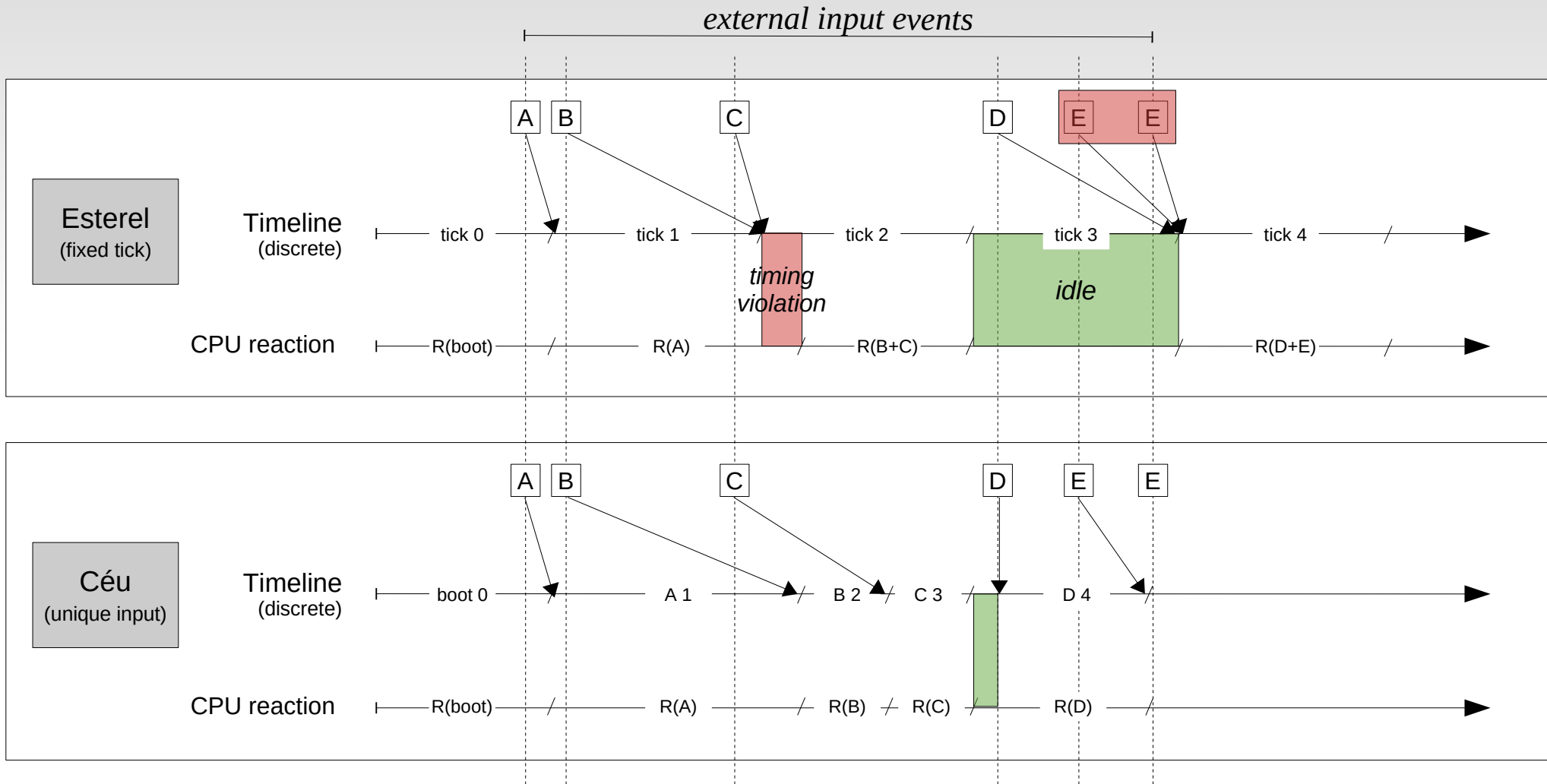
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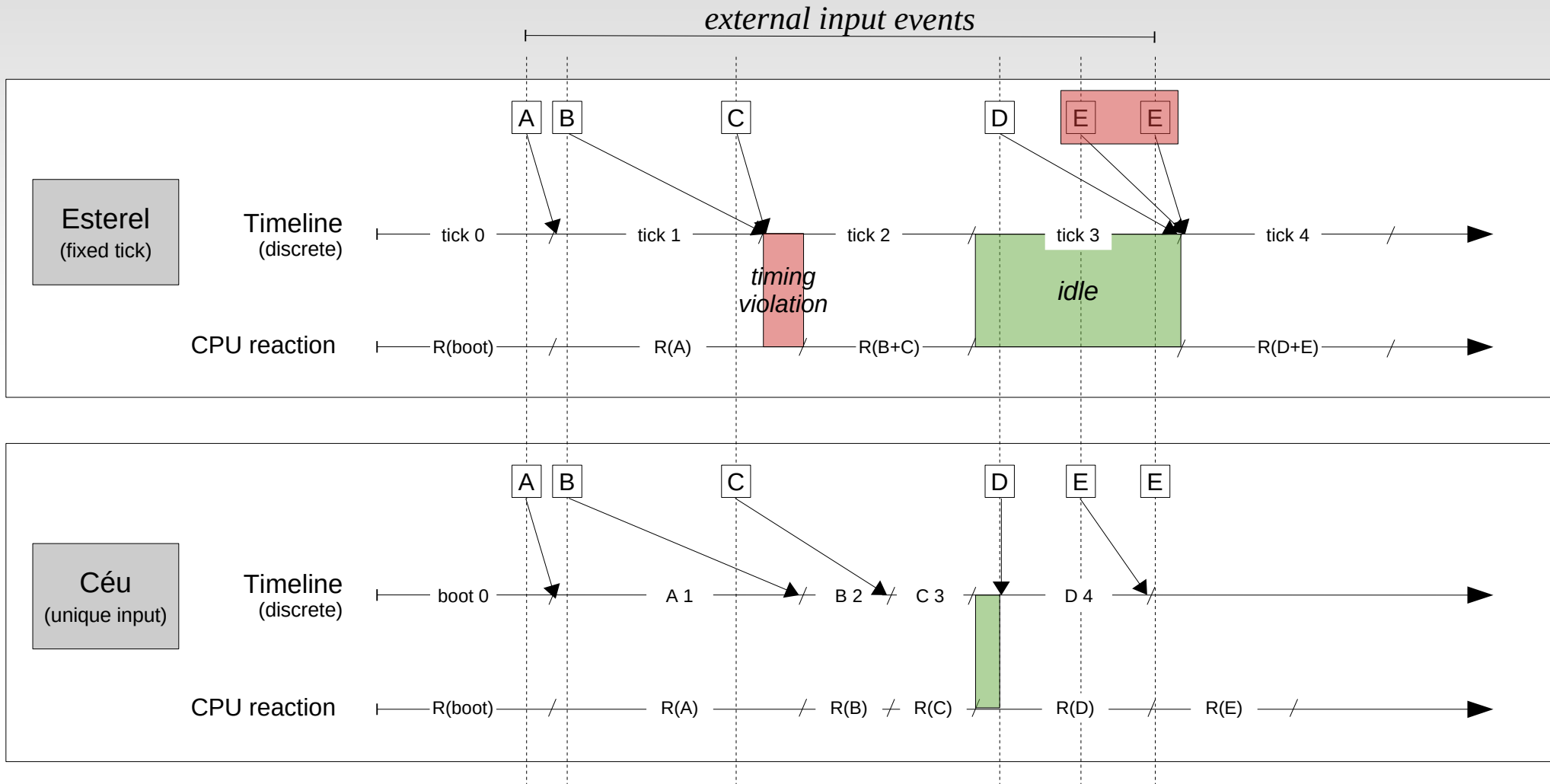
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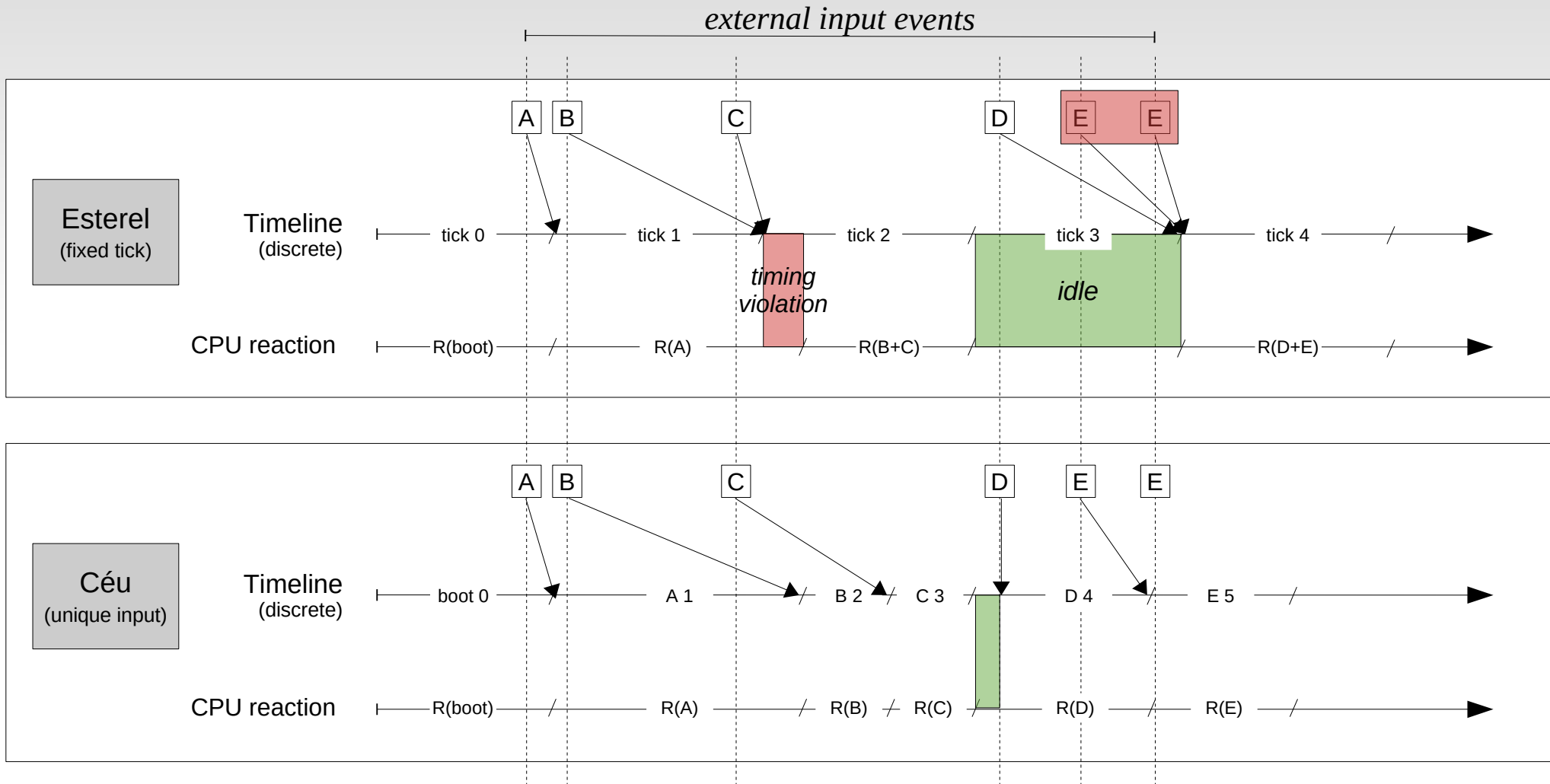
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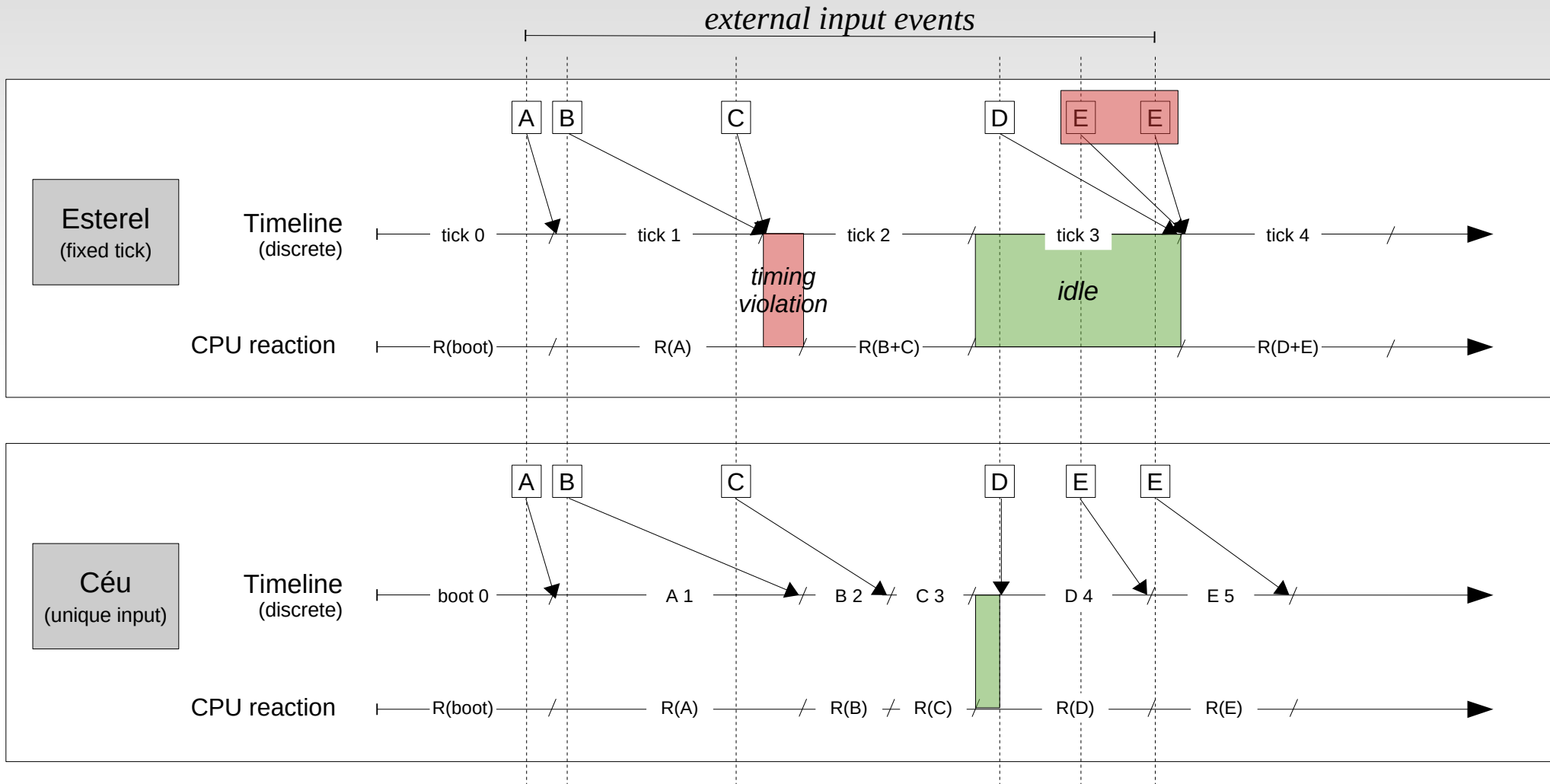
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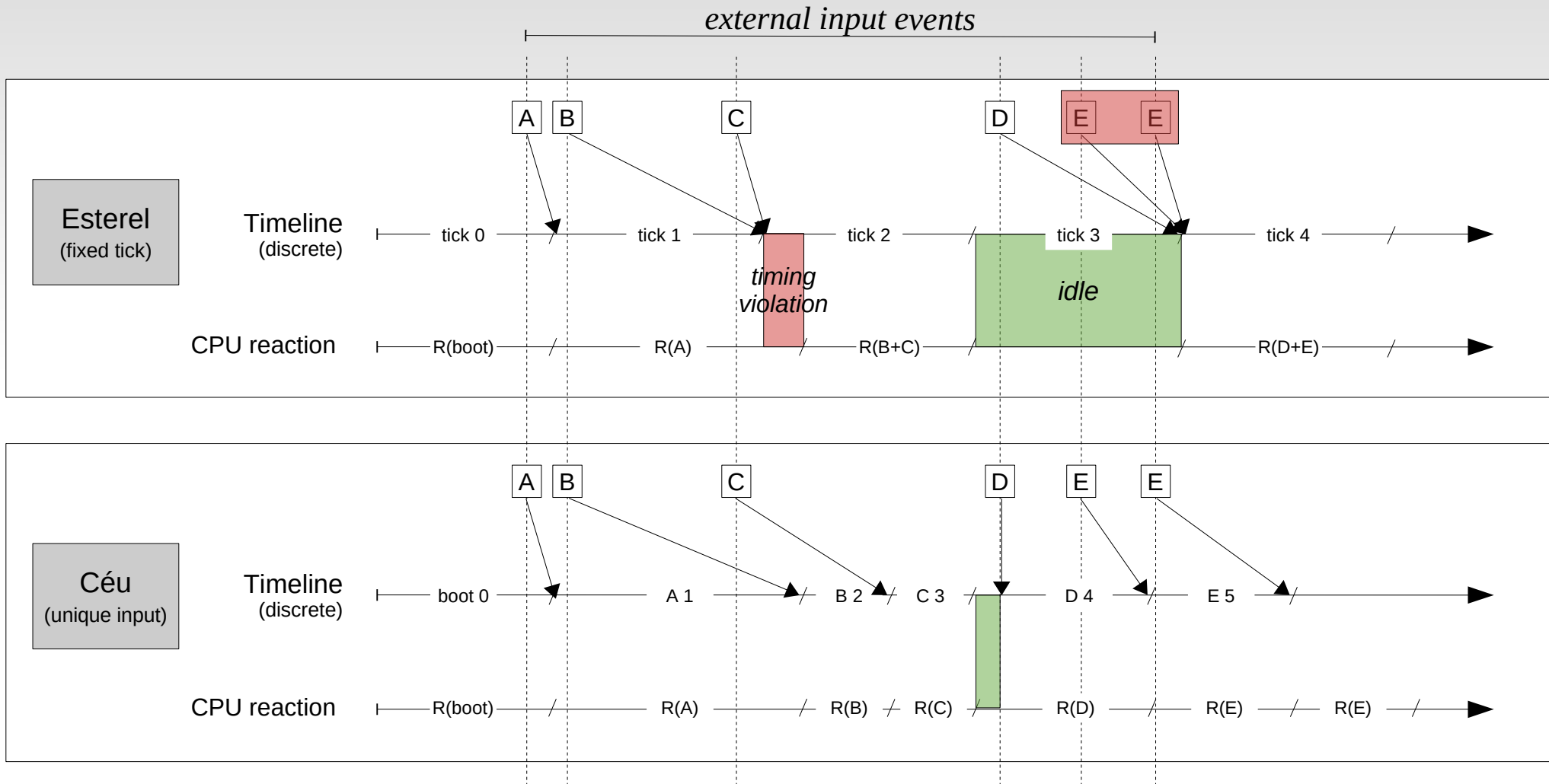
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