TinyTimber

Johan Nordlander
johan.nordlander@dataductus.se
Data Ductus AB / Chalmers

Real-Time Systems EDA223

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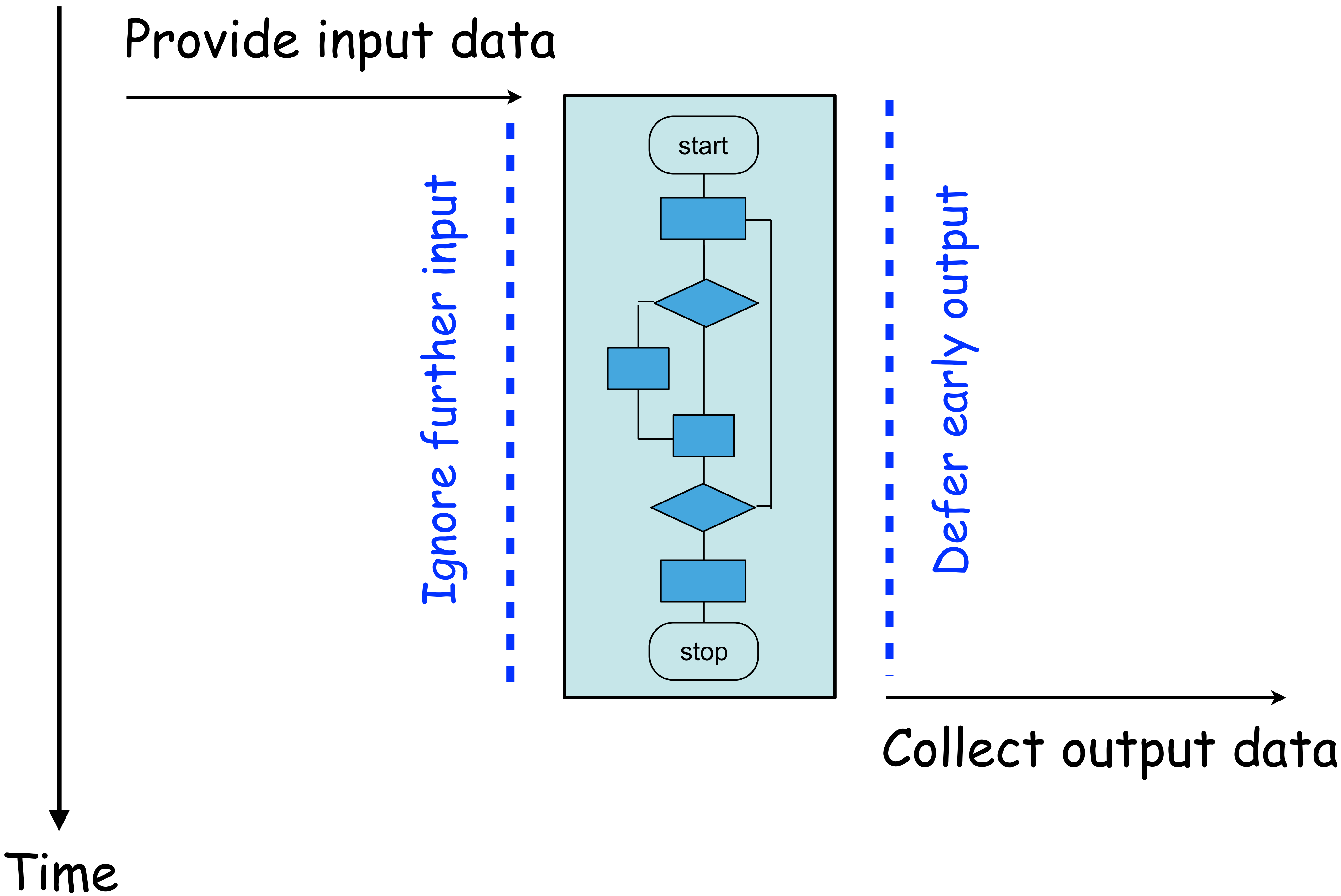
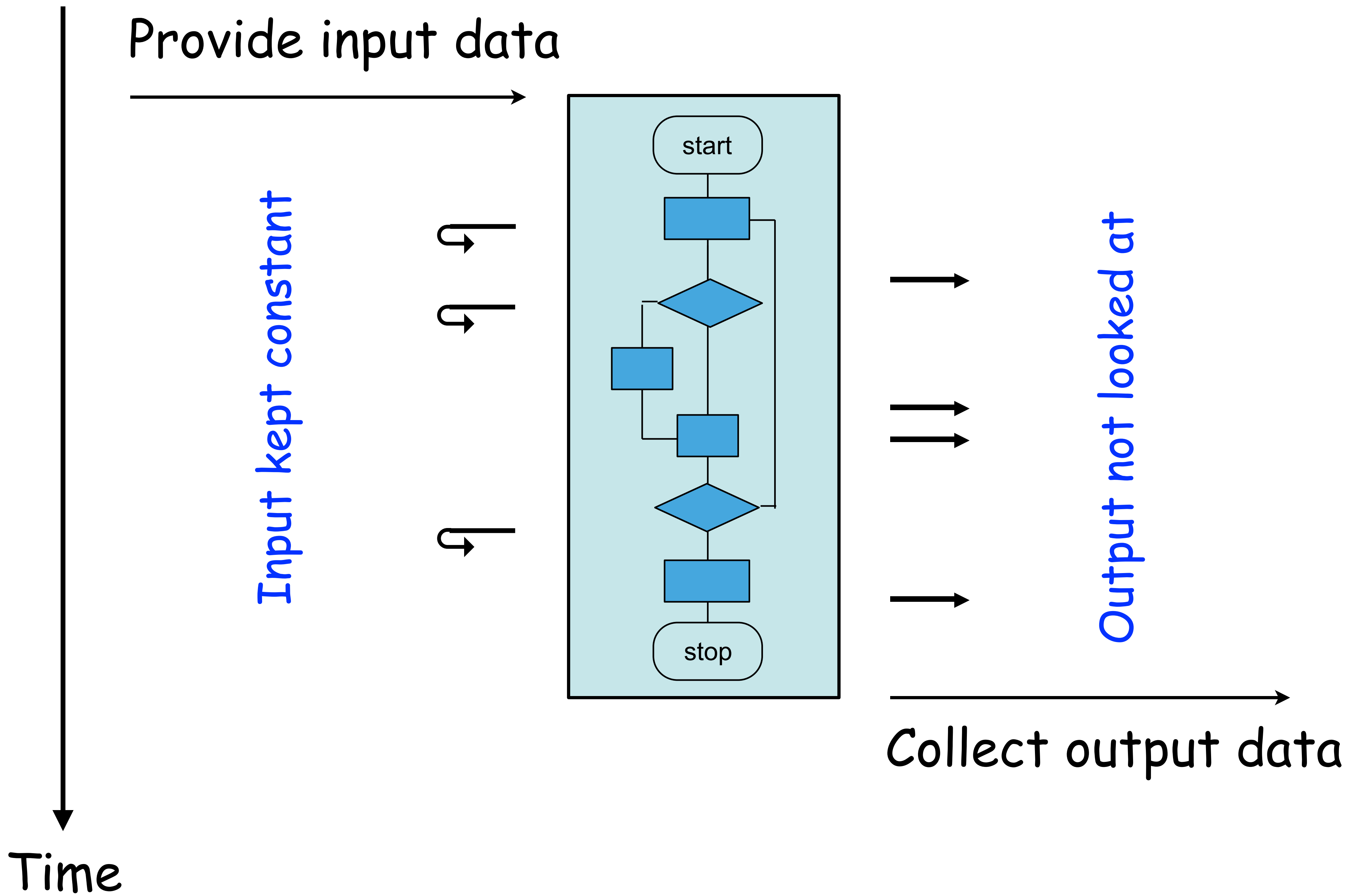
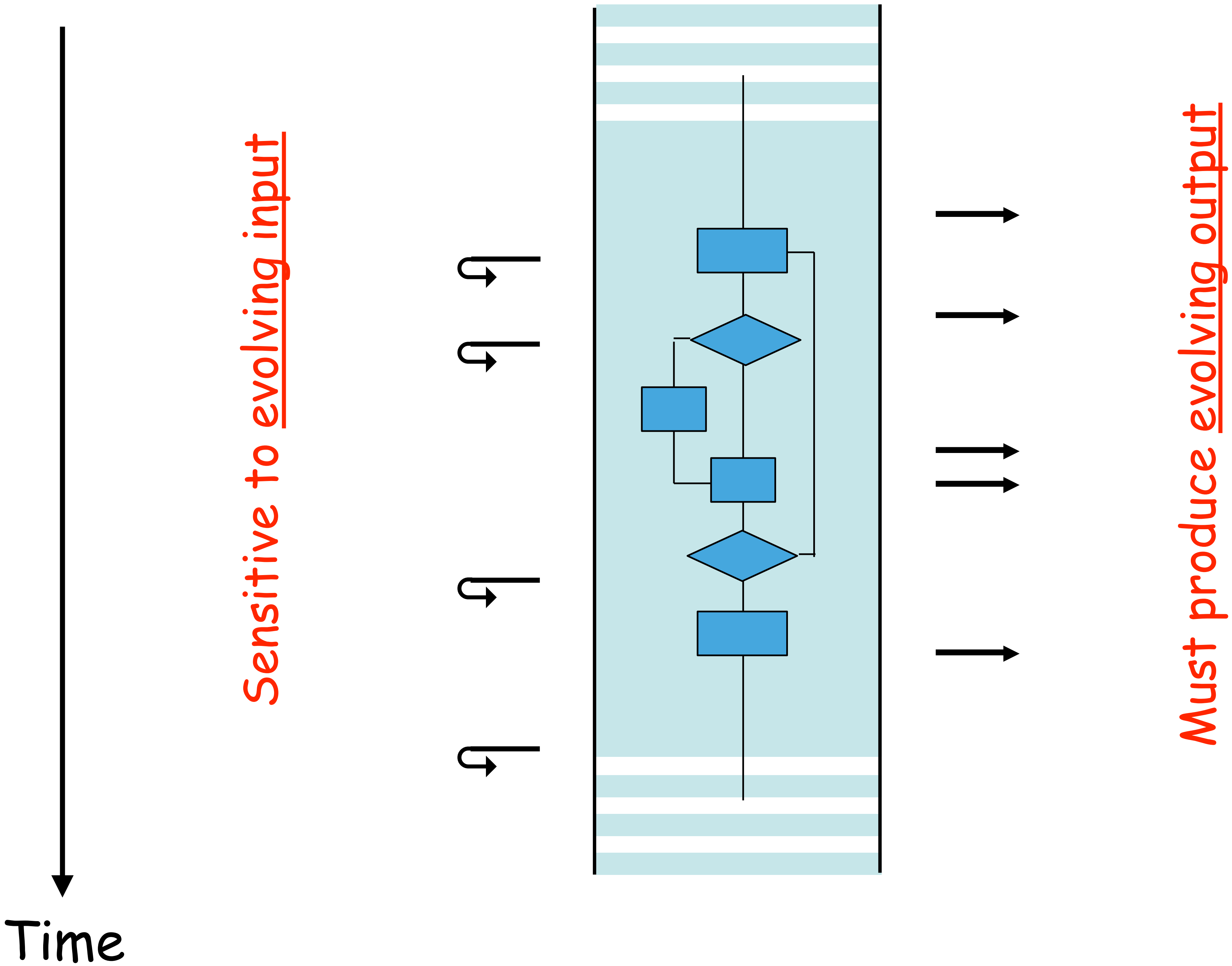
The classical program



In practice


Provide input data
start
stop
Input kept constant
Output not looked at
Collect output data
Time

Modern programs



Why?

- Because modern computers are components among other evolving components like
  - Keyboards, mice and displays
  - Human users behind these components
  - Network interfaces
  - Other computers behind these components
  - Sensors and actuators
  - Real physical objects behind these components
- Because a modern computer program is very rarely in superior control of its environment

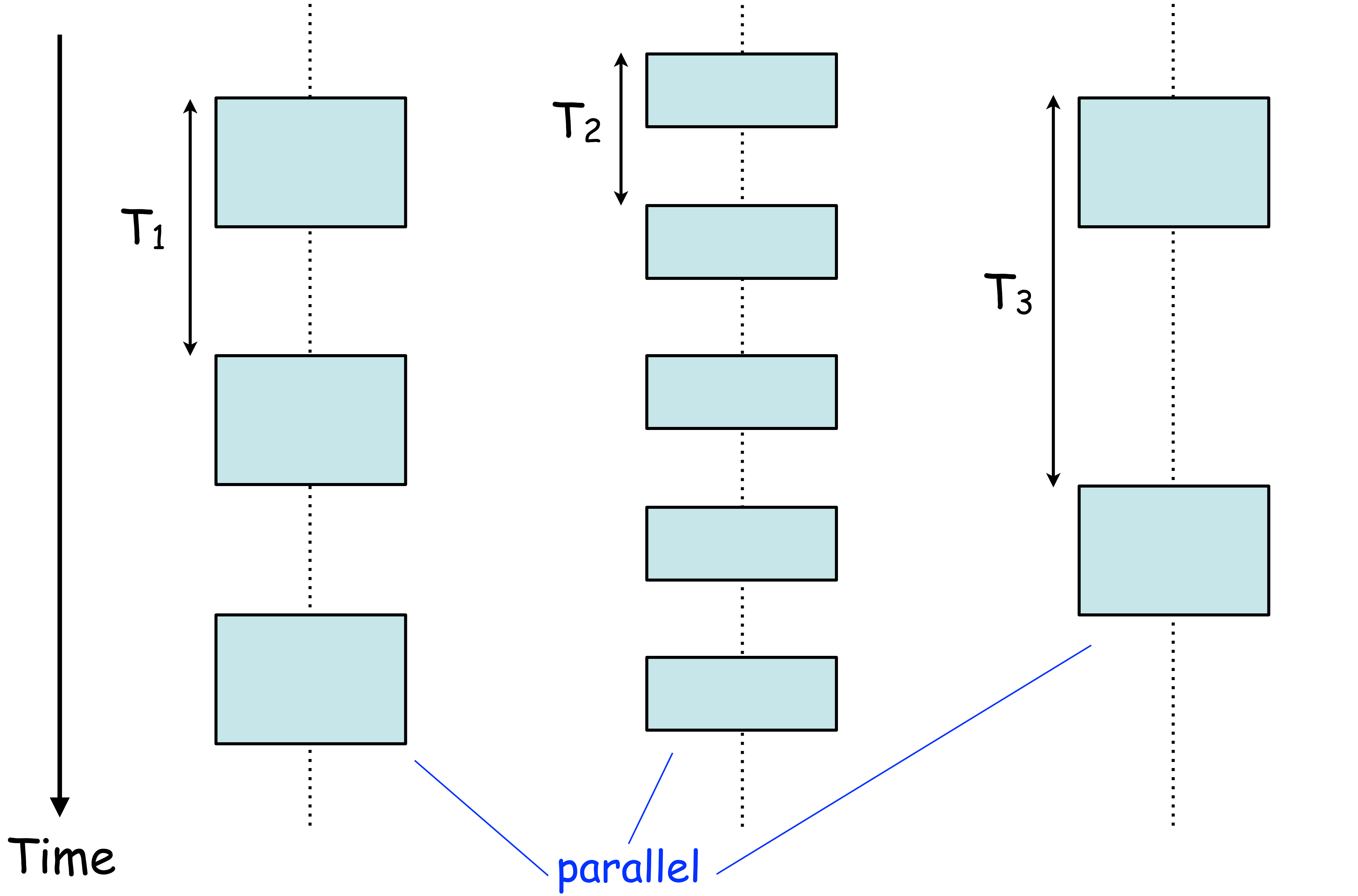
Dealing with evolving input

- Approach 1: New input is **read** from the environment at the initiative of the **program**
  - (As often as "possible"...)
  - (Or in an ad hoc fashion...)
  - Or at well-defined times!
- Approach 2: New input is **written** into the program at the initiative of the **environment**
  - (Just to be stored somewhere...)
  - Or guaranteed to trigger an associated reaction!

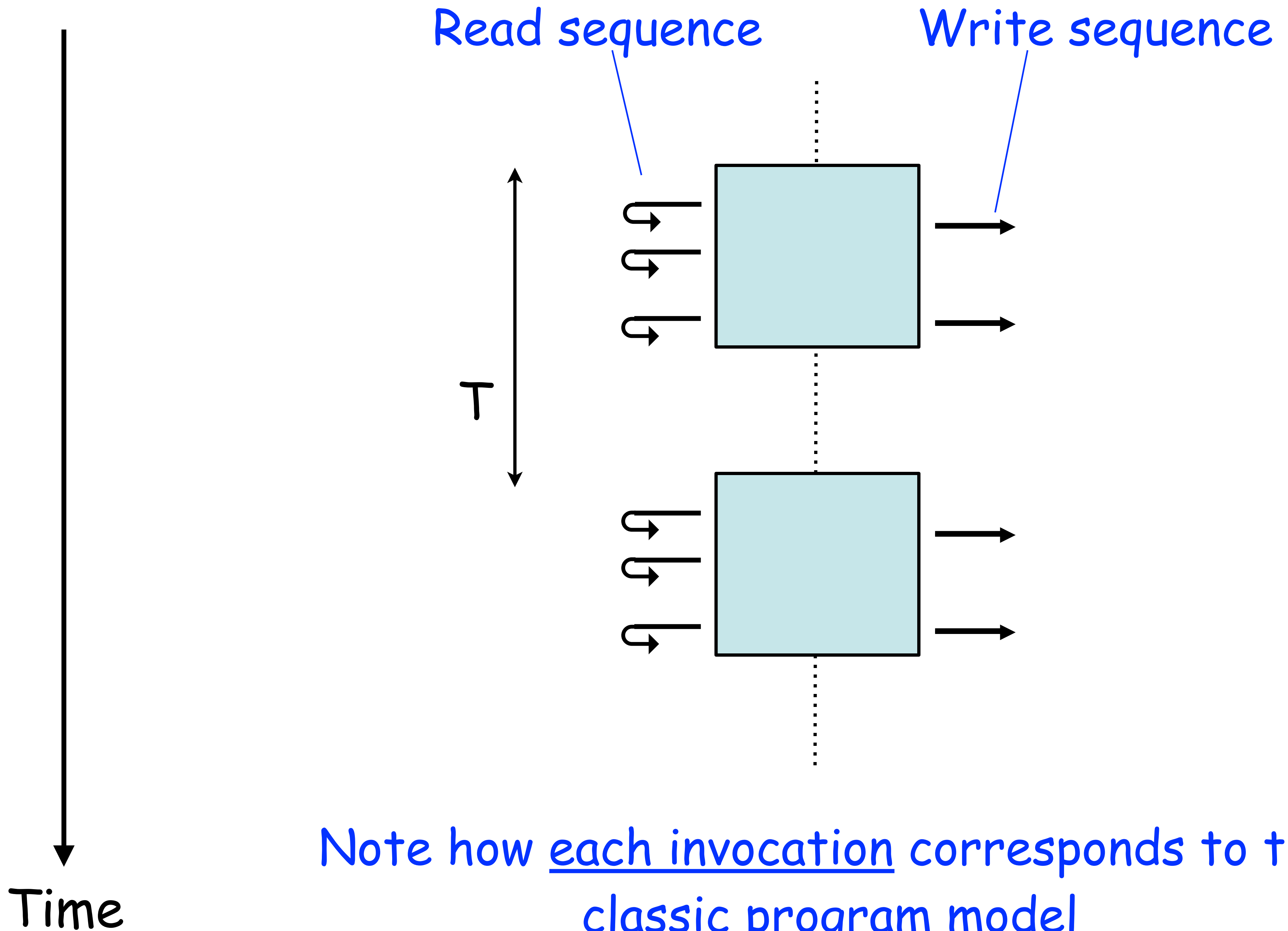
Approach 1: Time-triggered systems

- Idea: read input at pre-defined times, chosen to match the expected variations in input
- Obvious special case: read input every T time units (the periodic process)
- What happens between the computations? Nothing – the CPU can just shut down!
- How choose T? Use Nyqvist's sampling theorem!
- What if there are multiple inputs?
  - Let the highest frequency input determine T...
  - Or run multiple periodic processes in parallel!

Periodic time-triggered systems



Adding input/output

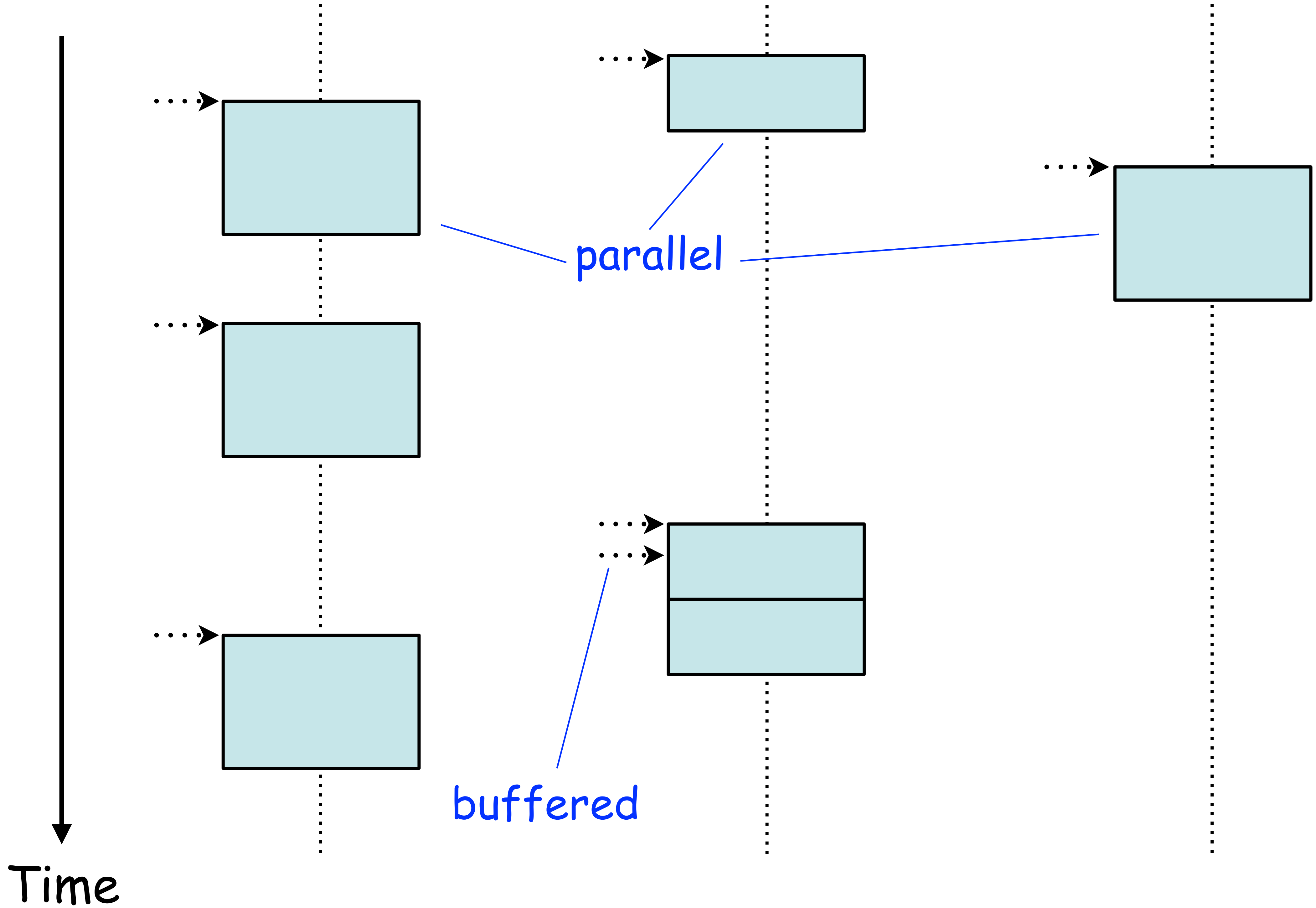


Note how <u>each invocation</u> corresponds to the classic program model

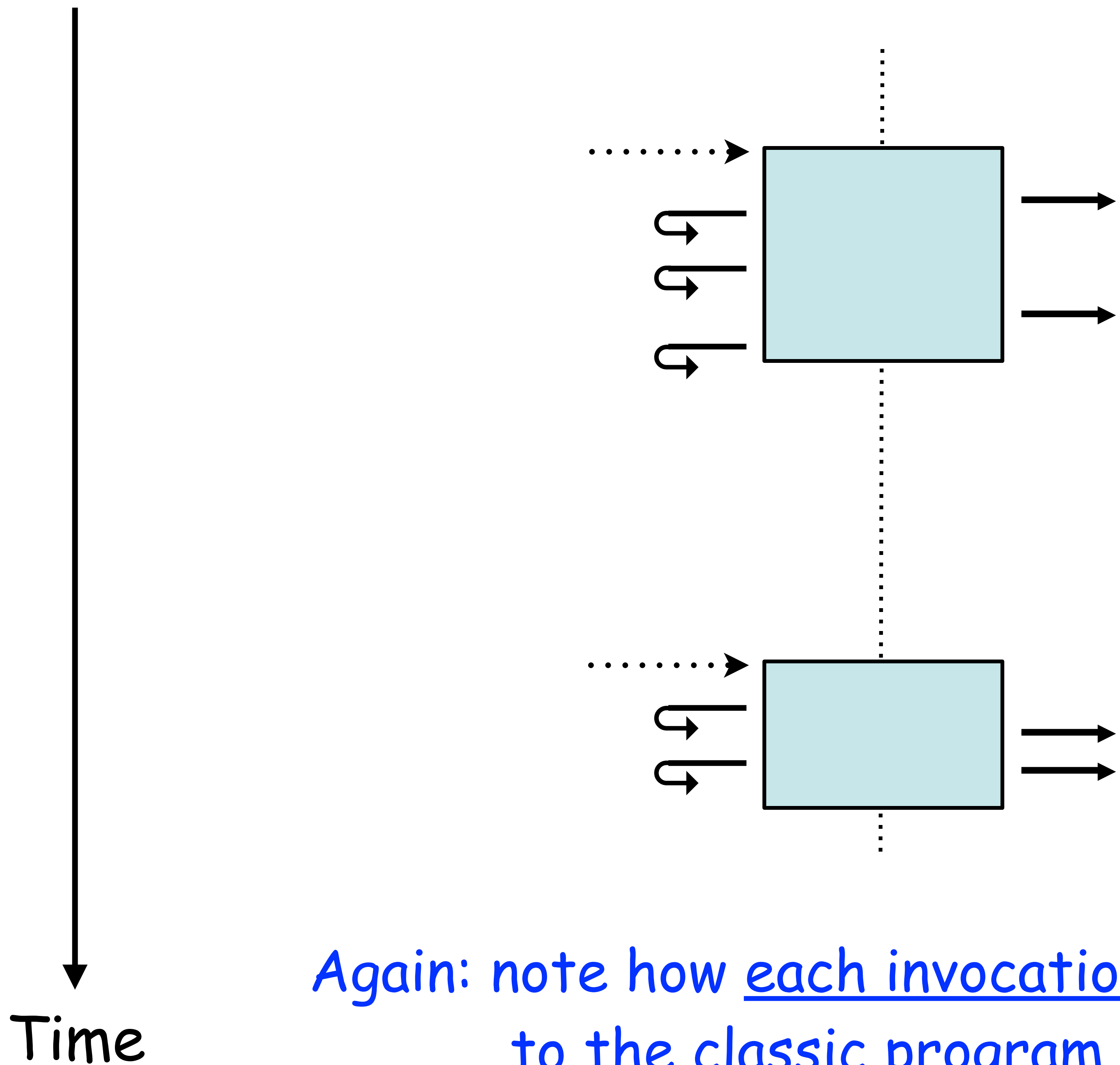
Approach 2: Event-triggered systems

- Idea: let the environment decide when input has changed enough to require some program action; i.e., when an event has occurred
- Well-known concept on the computer hardware level: the external interrupt!
- What happens between the event processing phases? Nothing – the CPU can just shut down!
- What if there are events with overlapping reactions?
  - Buffer up the events...
  - Or run multiple event-handlers in parallel!

Event-triggered systems

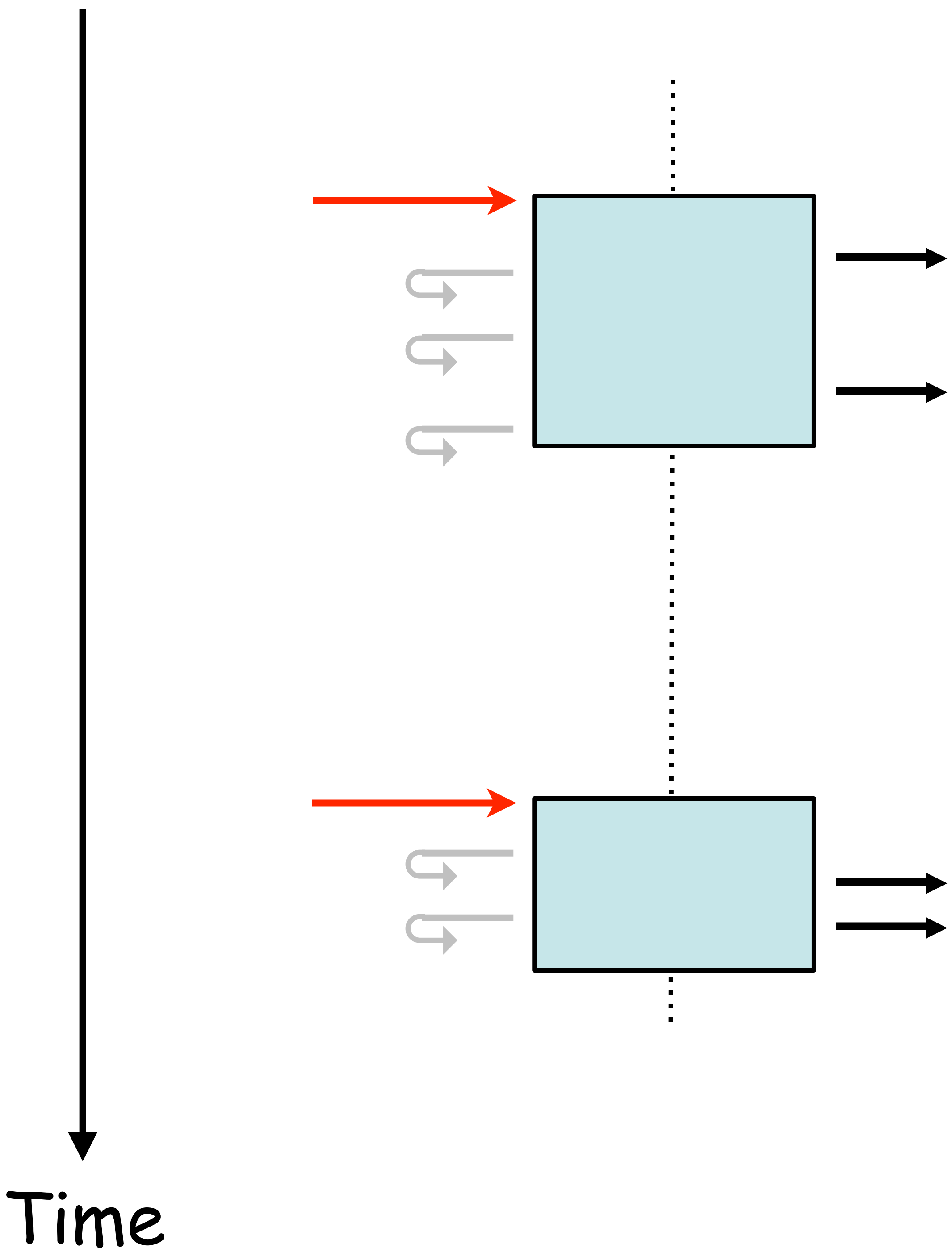


Adding input/output



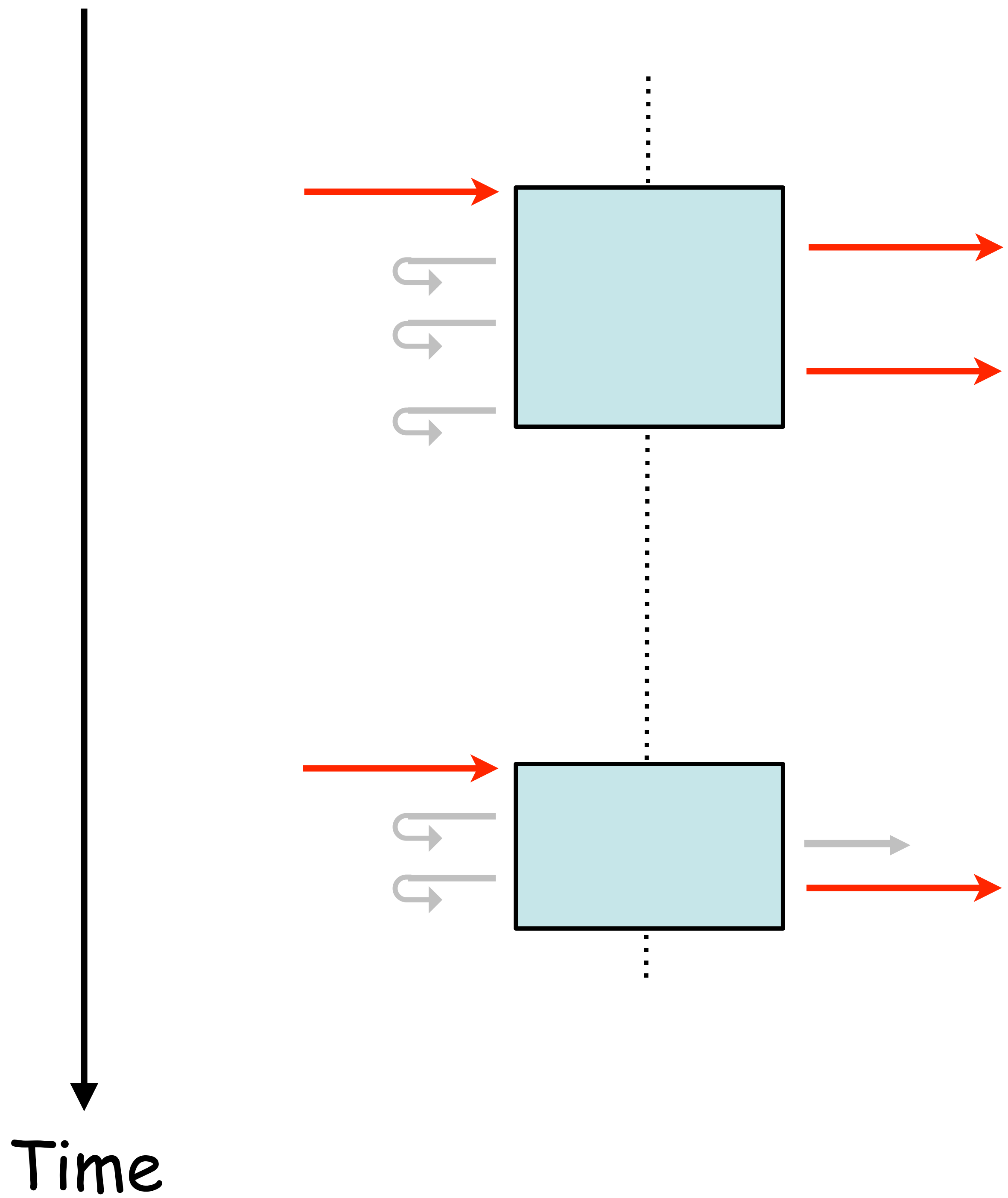
Again: note how each invocation corresponds to the classic program model!

Adding input/output



New option: let the events carry input data as well

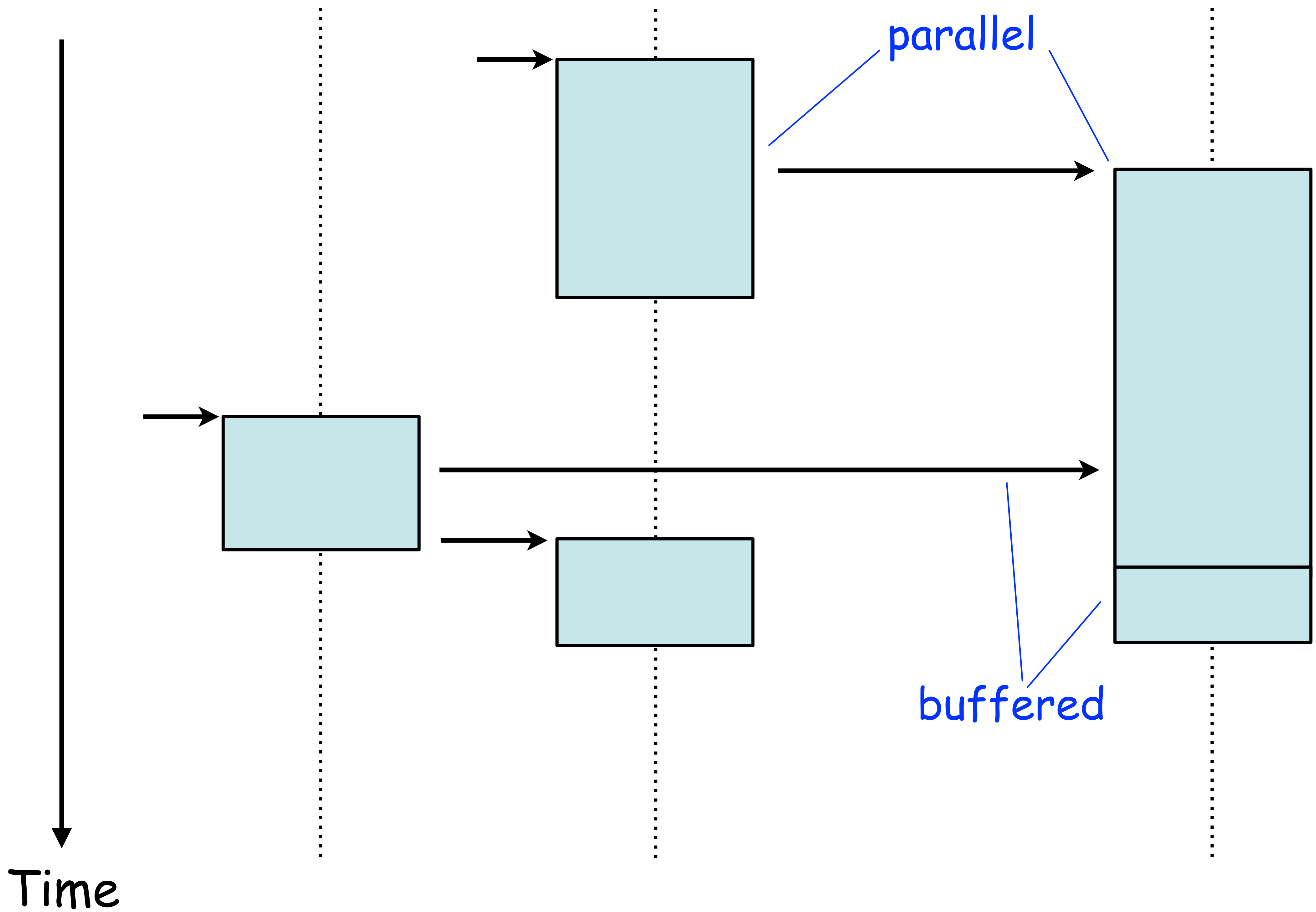
Adding input/output



New option: let the events carry input data as well

New option: let some write operations trigger new events!

Chains of events



Time- vs. event-triggered systems

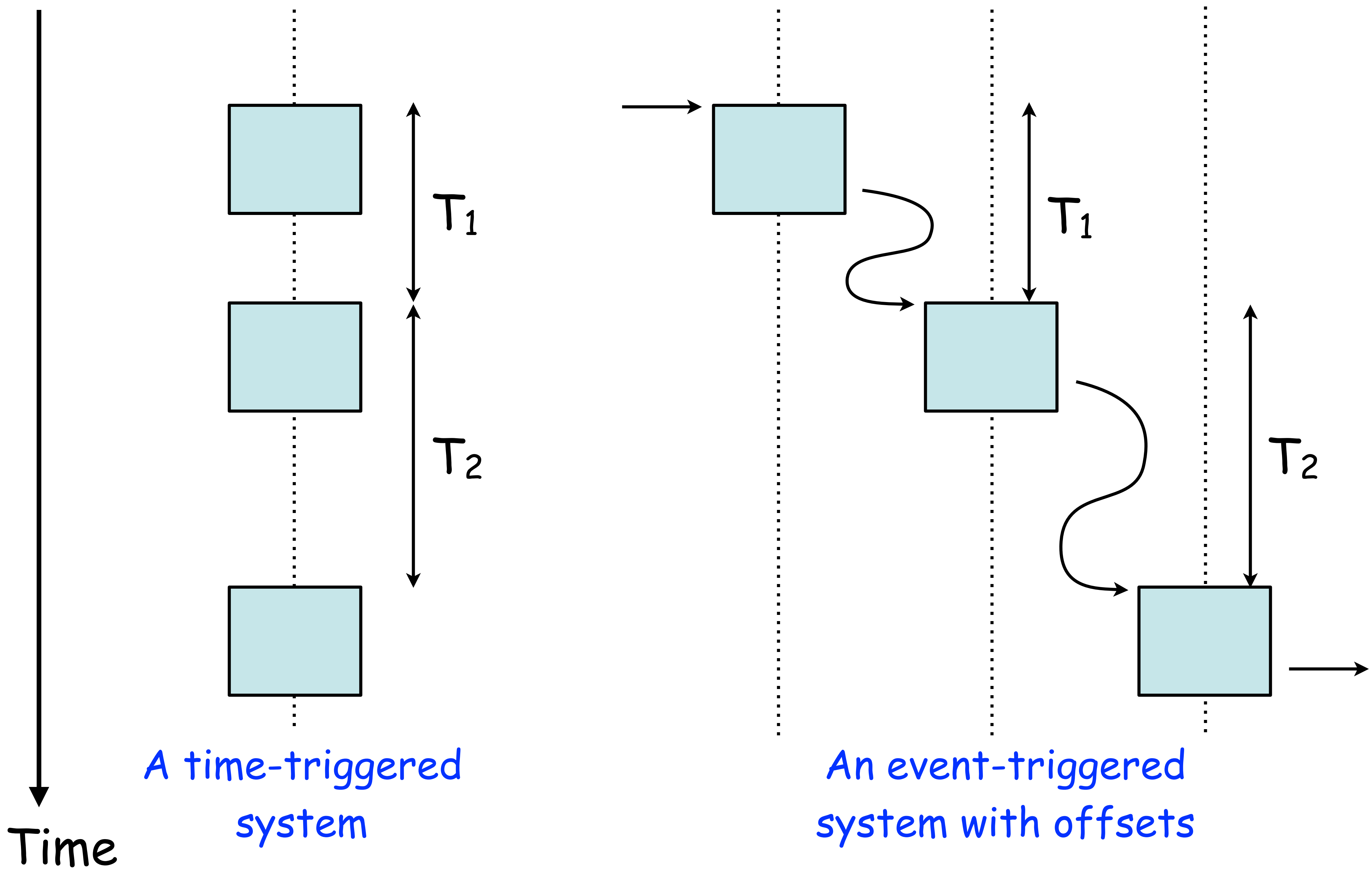
Time-triggered systems observe the environment and take action on basis of the changes they see.

Suitable when input may be constantly changing and all value are equally interesting, like in control systems

Event-triggered systems are controlled by the environment, and take action when the environment so decides.

Suitable when interesting input values are highly irregular, or when it is already discrete, like in communication systems

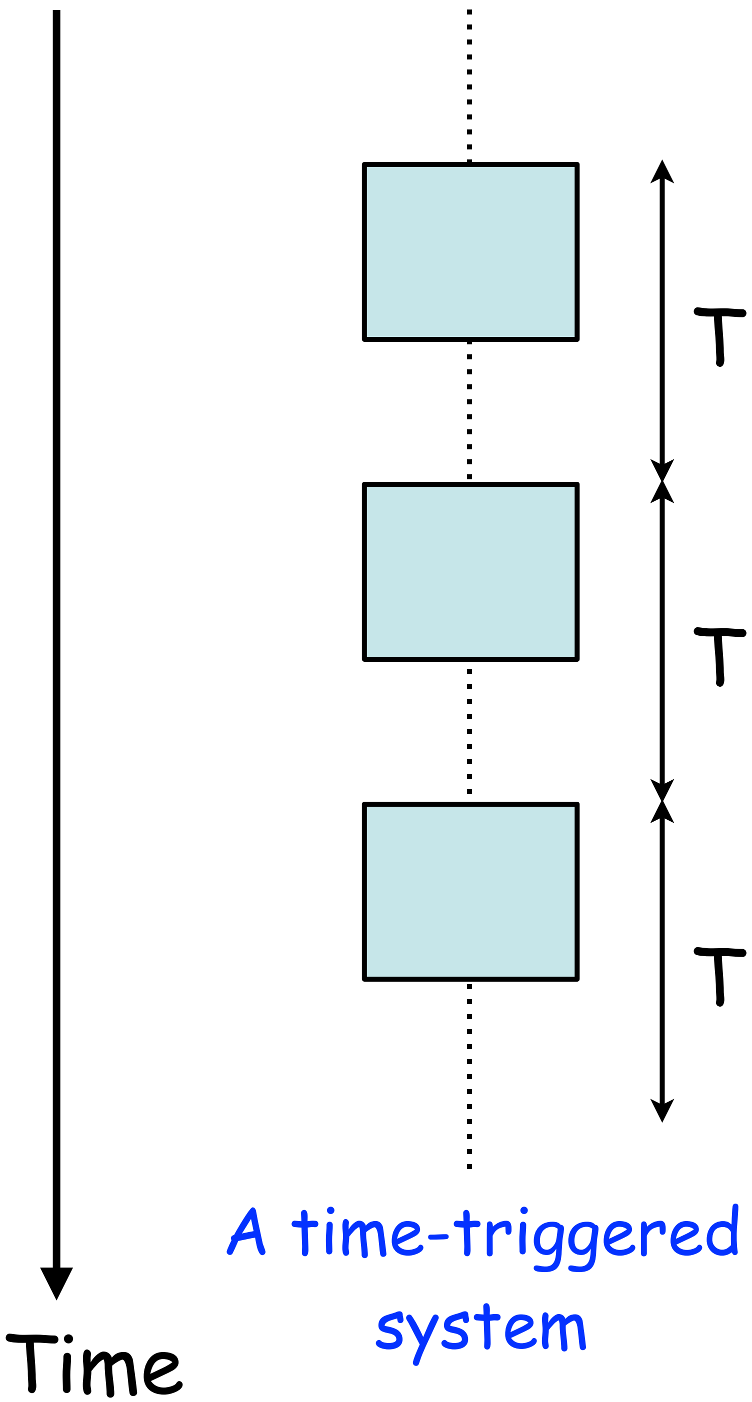
(1) If we allow events with offsets...



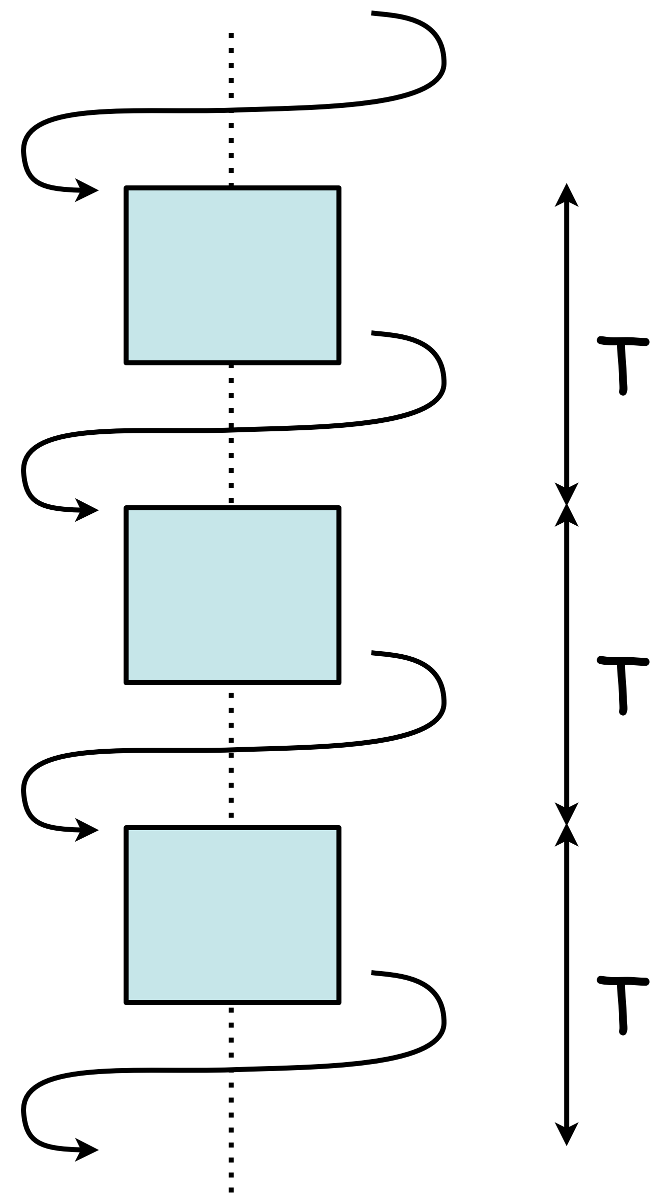
A time-triggered system

An event-triggered system with offsets

(2) If we allow self-referencing…

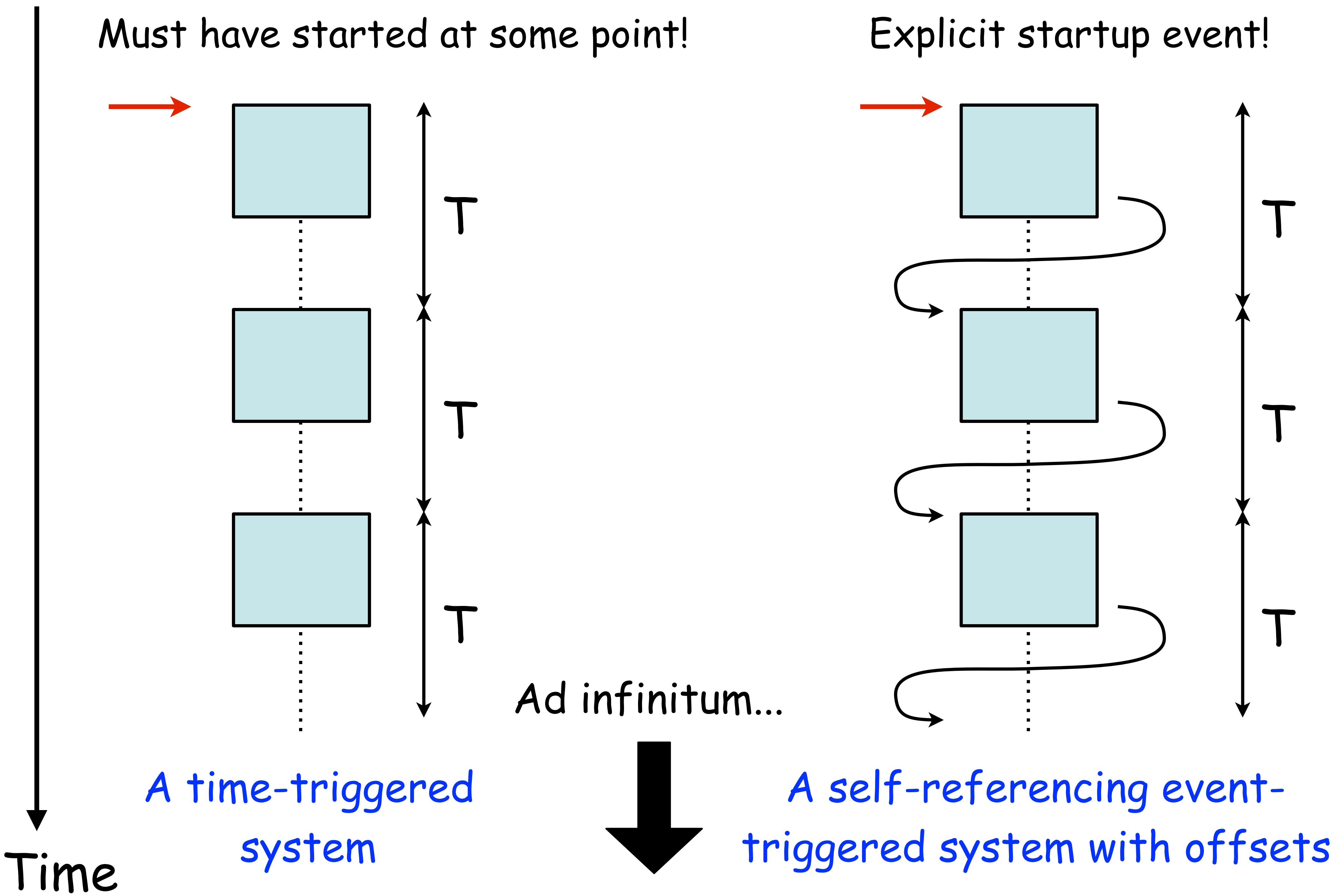


A time-triggered system



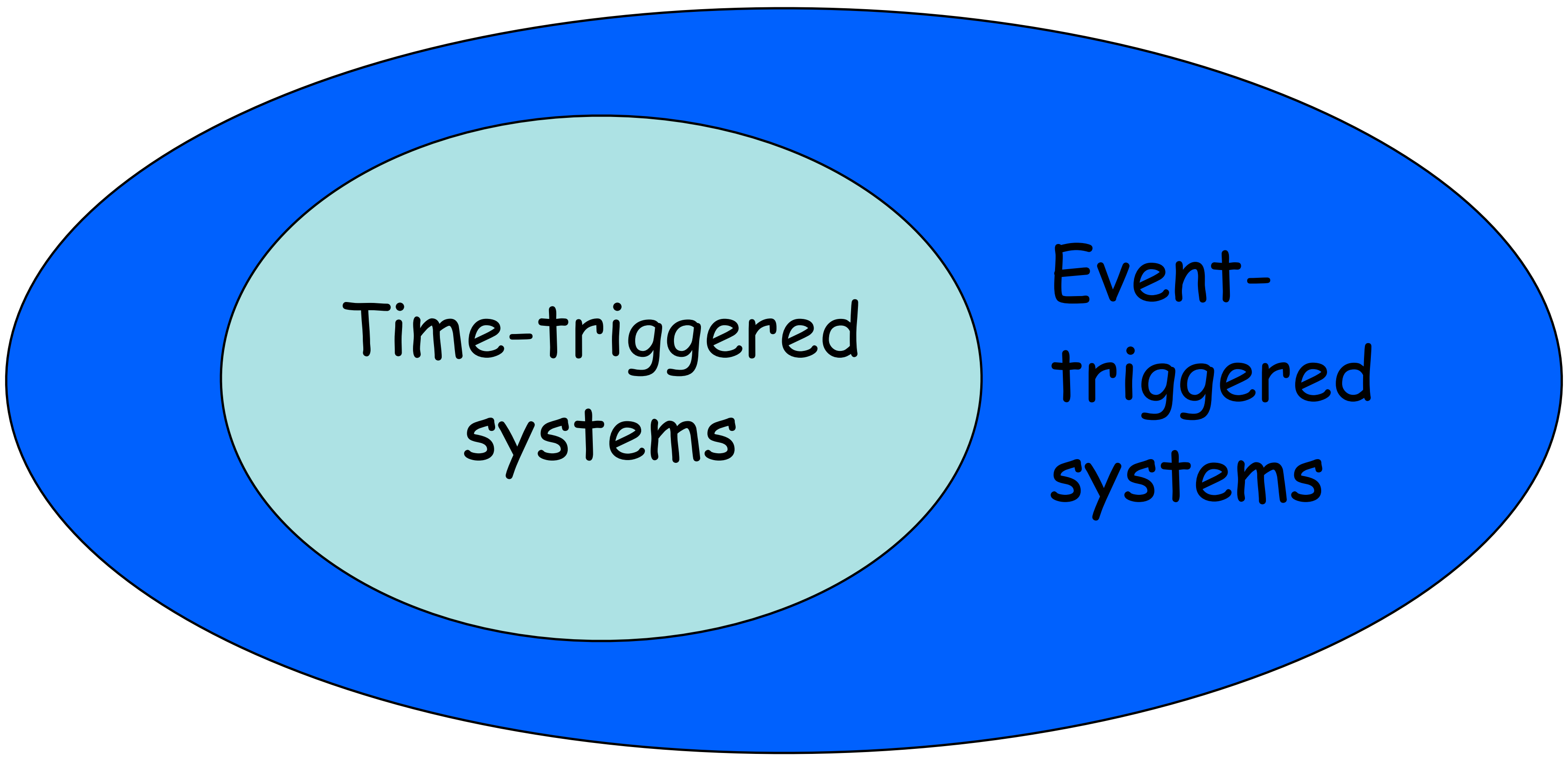
A self-referencing event-triggered system with offsets

(3) If startup is made explicit...



Then:

Time-triggered behavior emerges as a special case of an event-triggered system!



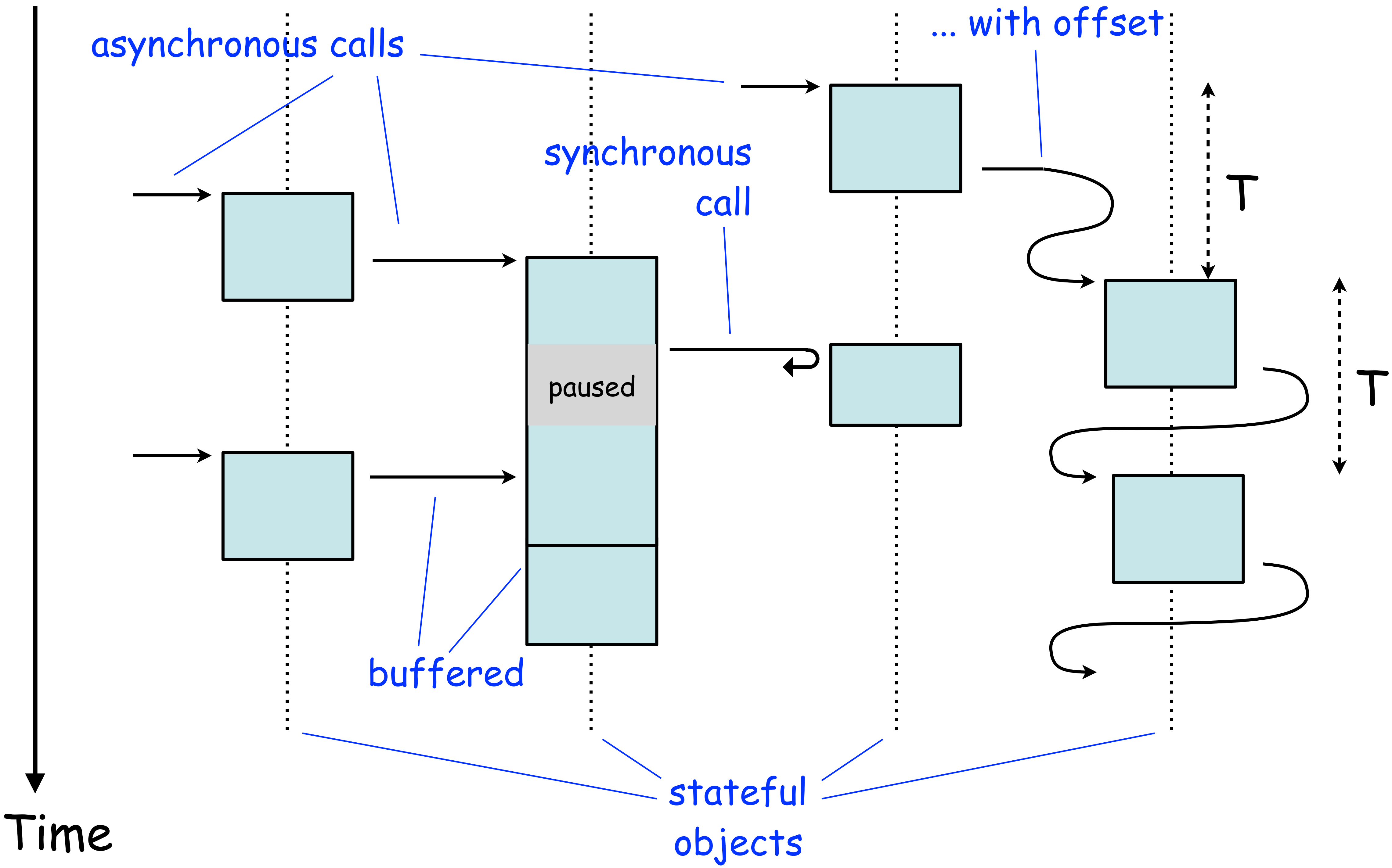
Time-triggerering as a special case

- A time-triggered behavior is just a chain of event reactions, separated by well-defined time offsets
- A periodic process is such a chain-reaction that oscillates (produces as many new events as those it reacts to)
- Many hybrid variants exist between the extremes of one single reaction and the oscillating periodic behavior
- Allows us to seamlessly study trade-offs between the basic approaches
- Note: not the commonly taught real-time systems view!
- It is however the view we find in TinyTimber!

TinyTimber

- A run-time kernel + a design style for programming embedded real-time systems in C
- Also a cut-down variant of the programming language Timber (timber-lang.org)
- Basic ideas:
  - Events can be triggered with time offsets
  - Events = **asynchronous method calls**
  - Methods belong to **objects**
  - Objects = protected sets of state variables
  - Also: **synchronous** method calls (mimic read/write)

A TinyTimber run-time scenario



In concrete C

Contructor definition

```
#define initCounter(en) { initObject(), 0, en }
```

```
typedef struct {
    Object super;
    int value;
    int enabled;
} Counter;
```

State layout

```
int inc( Counter *self, int arg ) {
    if (self->enabled)
        self->value = self->value + arg;
    return self->value;
}
int enable( Counter *self, int arg ) {
    self->enabled = arg;
    return 0;
}
```

Method definitions

```
Counter cA = initCounter(1);
Counter cB = initCounter(0);
```

Creating global instances

Calling methods

```
... ASYNC( &cA, inc, 1 ); ...

... int r = SYNC( &cA, inc, 0 ); ...

... AFTER( SEC(2), &cB, enable, 1 ); ...
```

Asynchronous call

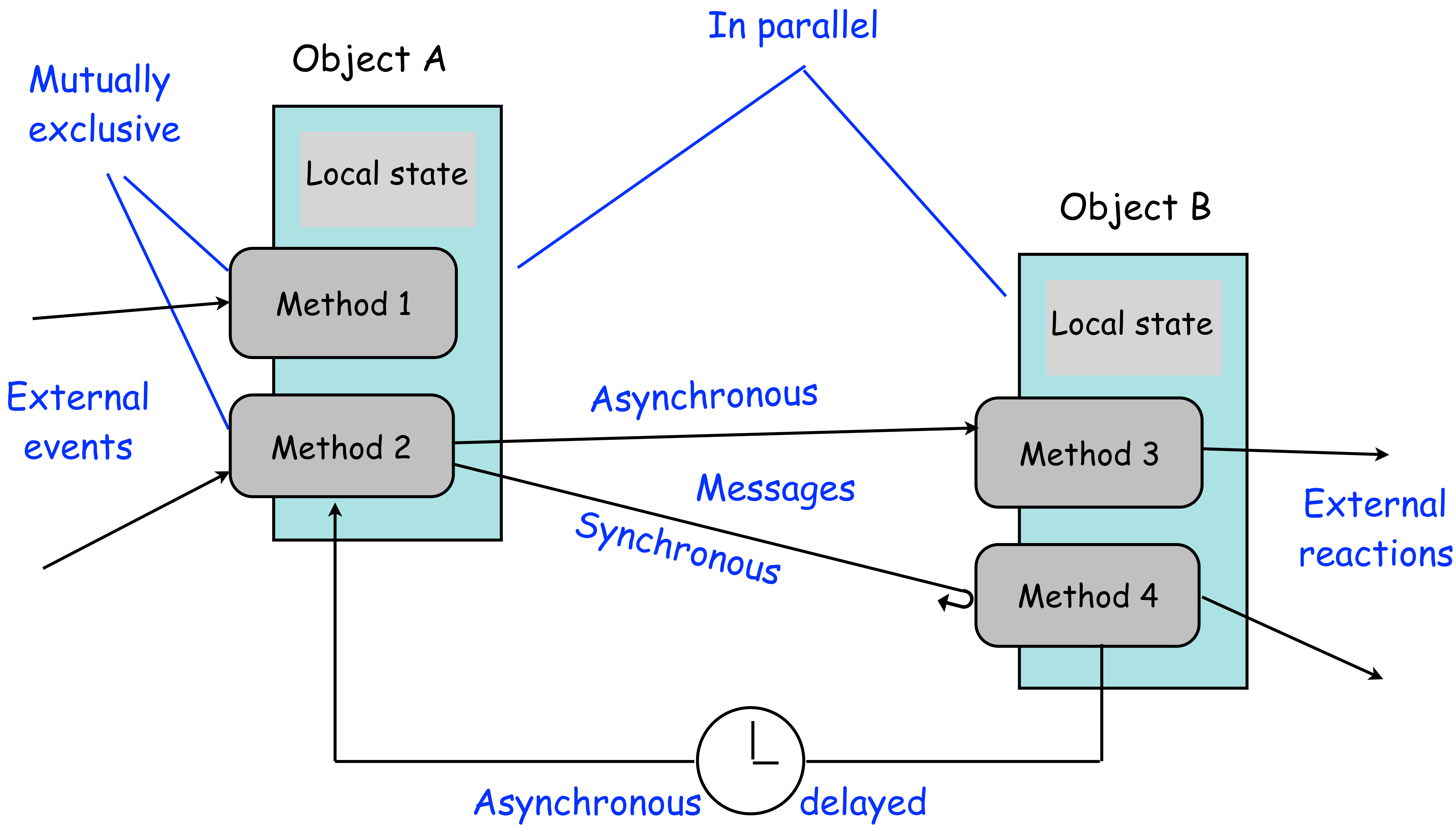
Synchronous call

Asynchronous call with offset

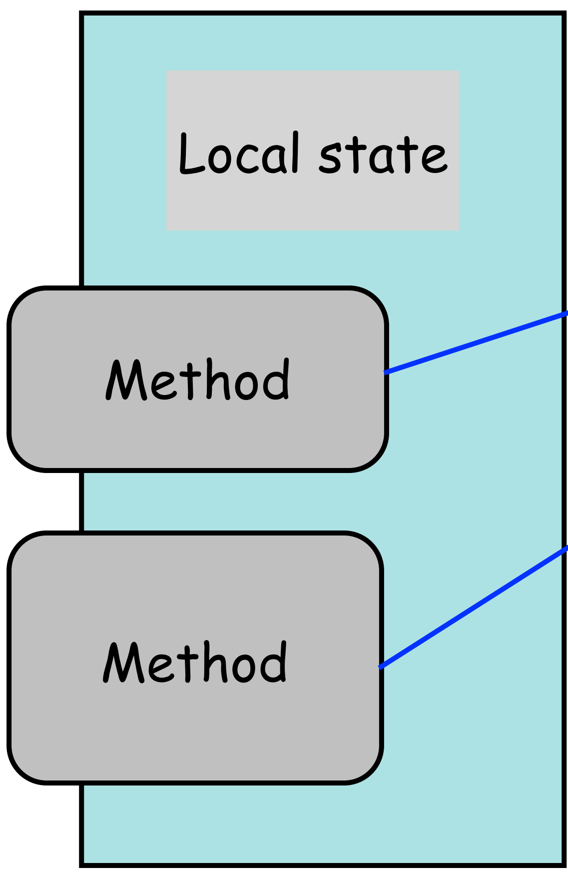
Top-level application setup

```
MyApplication app = initMyApplication();

int main() {
   INSTALL( &app, compute, IRQ1 );
   INSTALL( &cB, inc, IRQ2 );
   return TINYTIMBER( &app, reset, 0 );
}
```

Run-time execution model



Methods



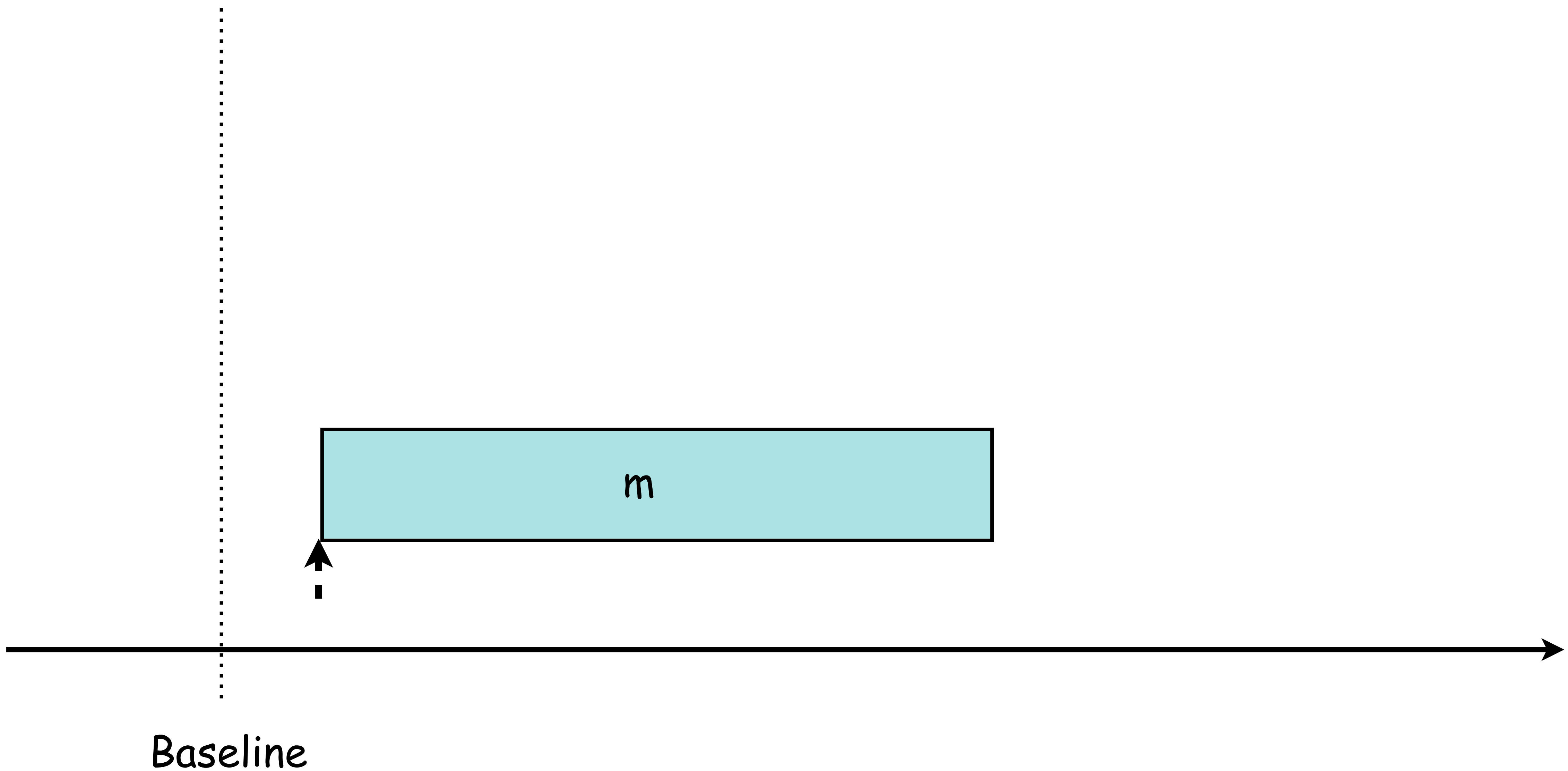
<u>Finite</u> sequences that

- Read and write local state
- Call other methods
- Perform local computations

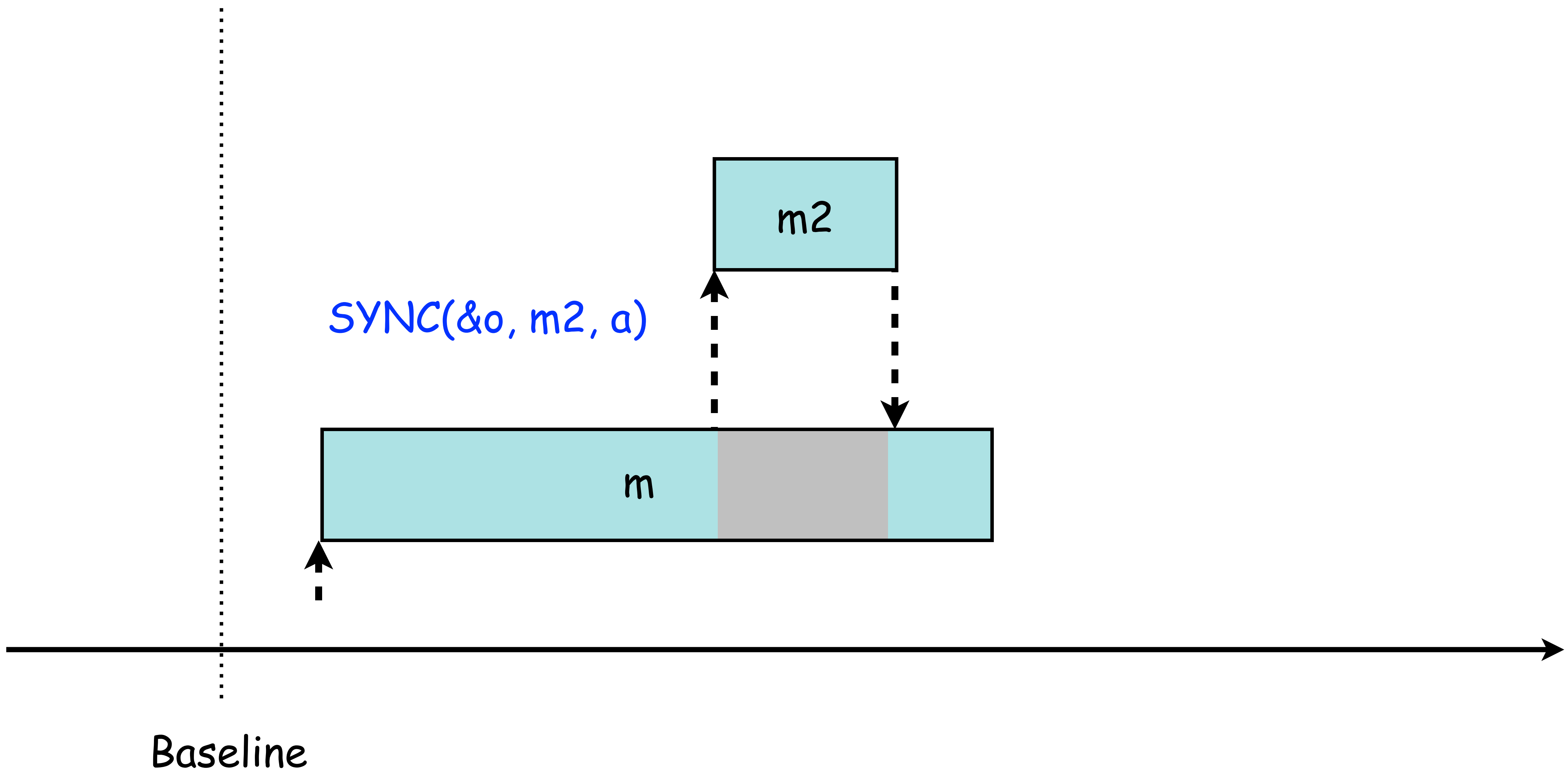
No indefinitely blocking operations,
no infinite loops:
objects <u>sleep</u> between <u>temporary</u> activity

The classical OO intuition recast to a concurrent setting!

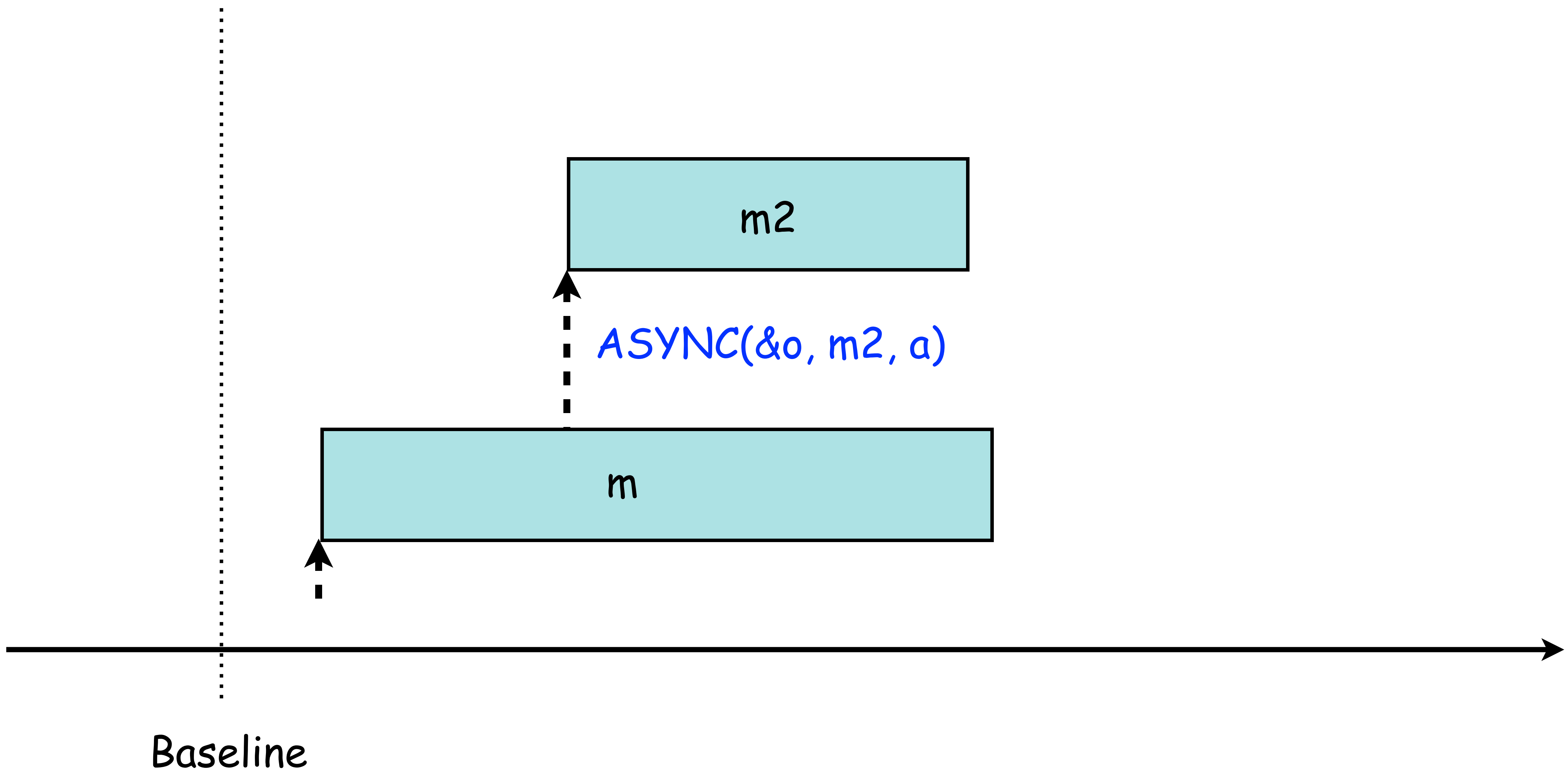
Timing reference



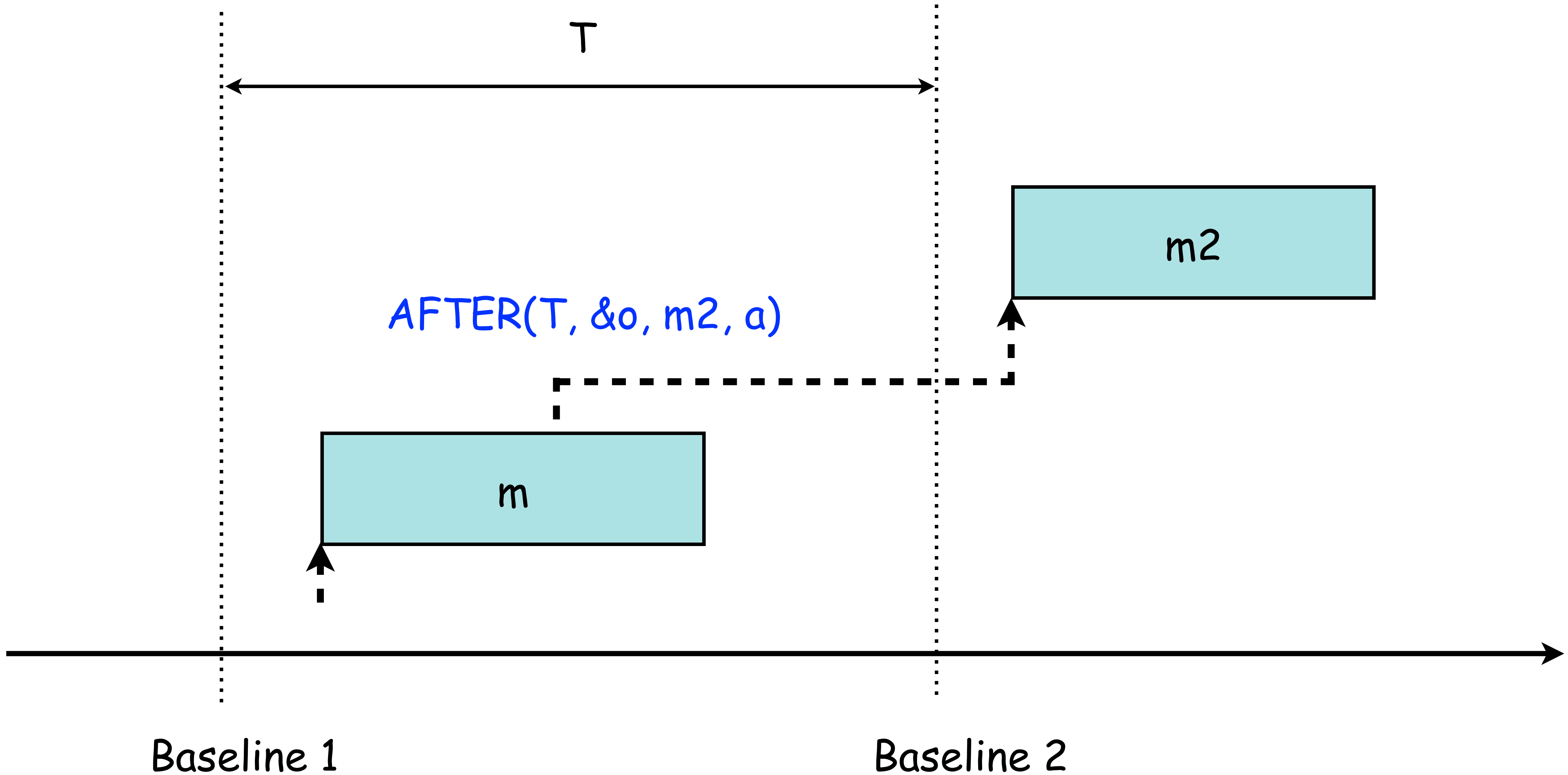
Timing reference



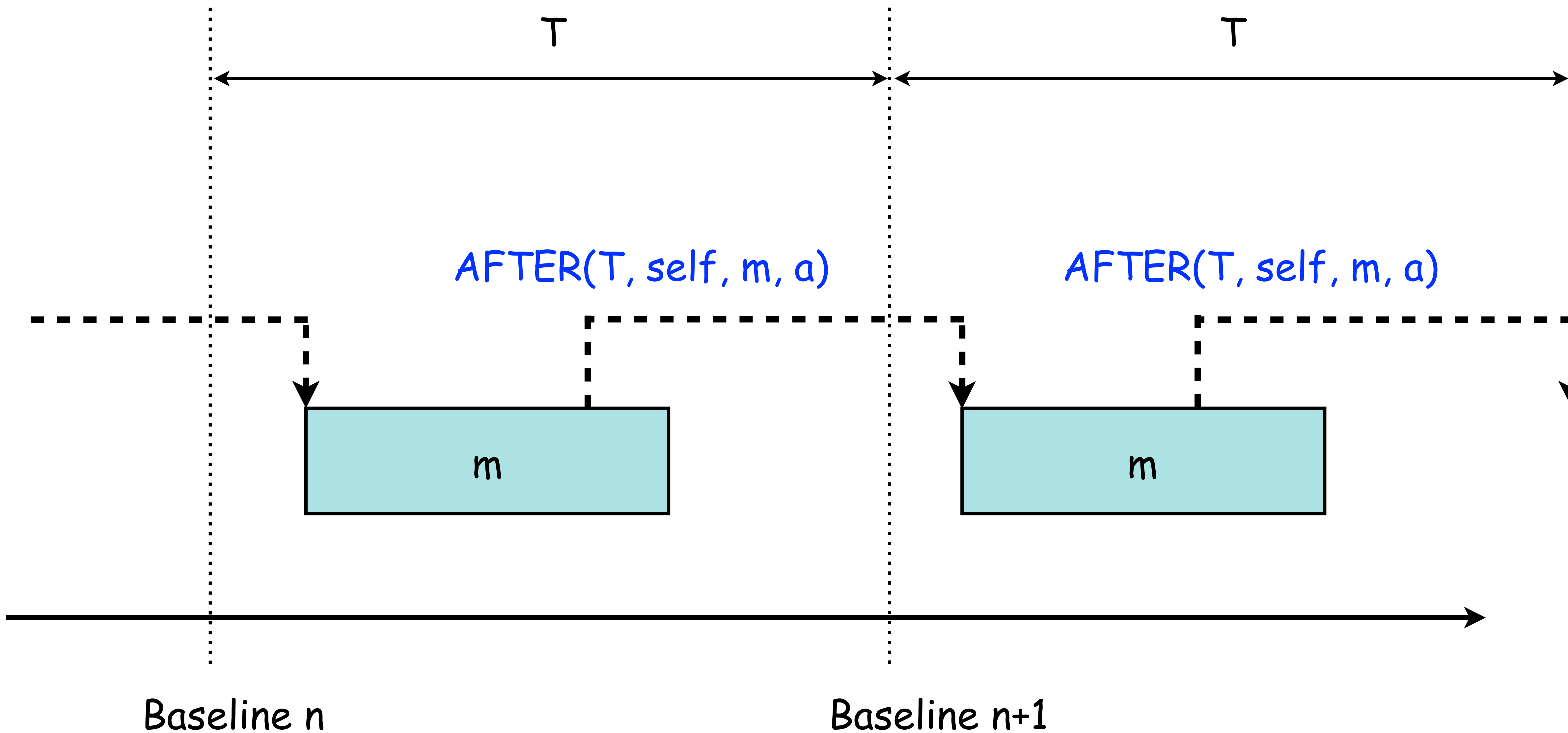
Timing reference



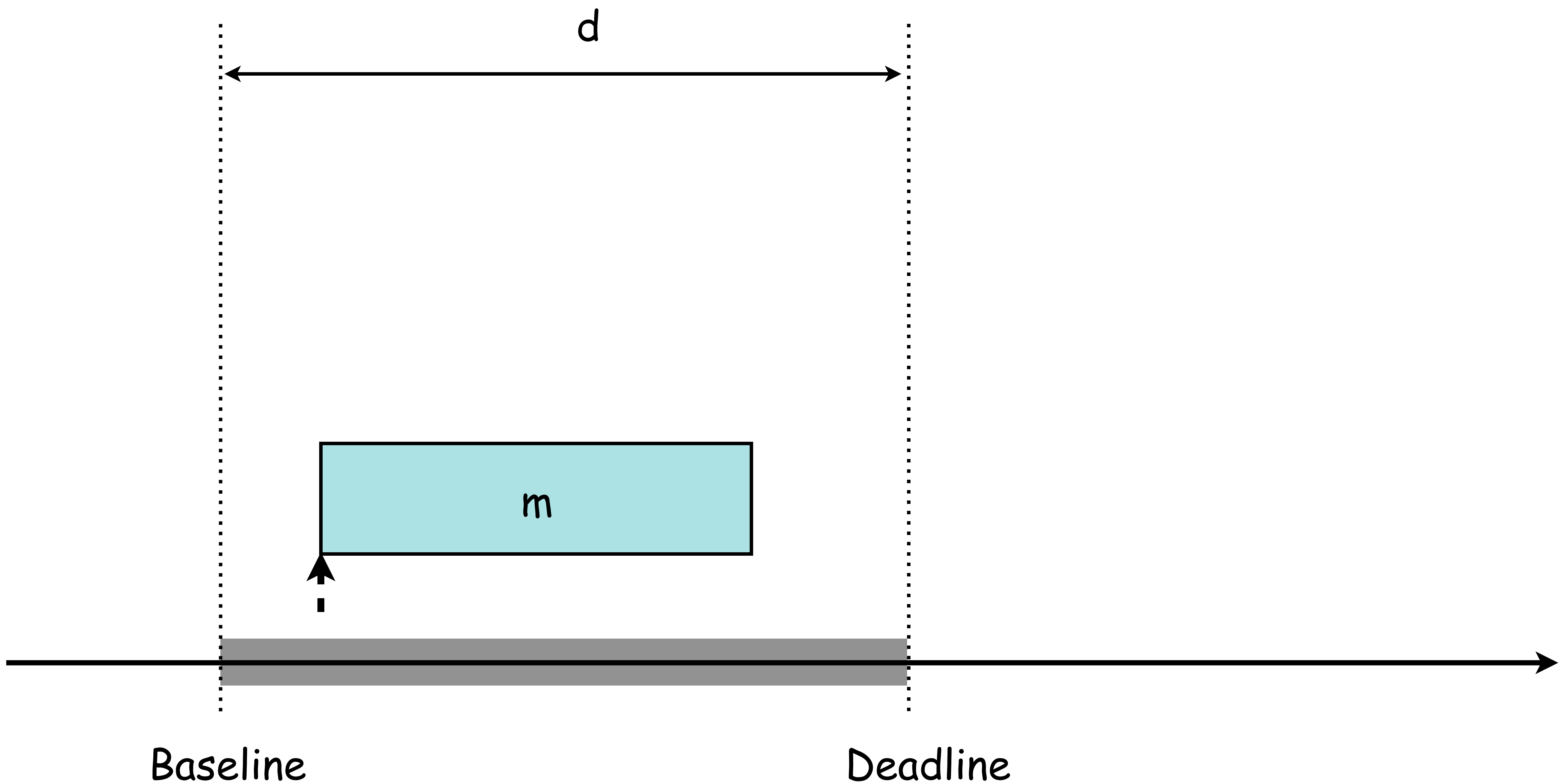
Baseline move



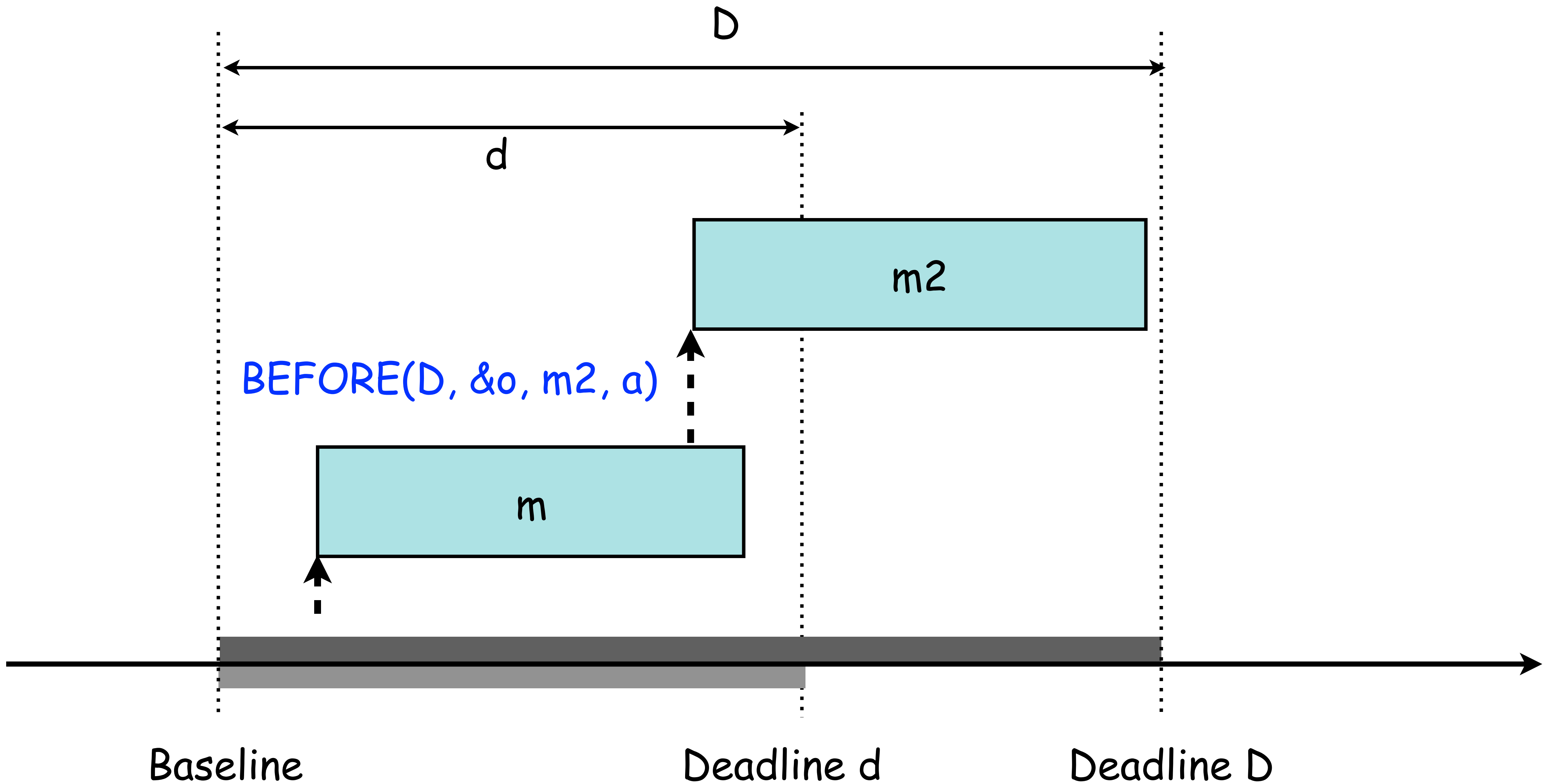
Periodicity



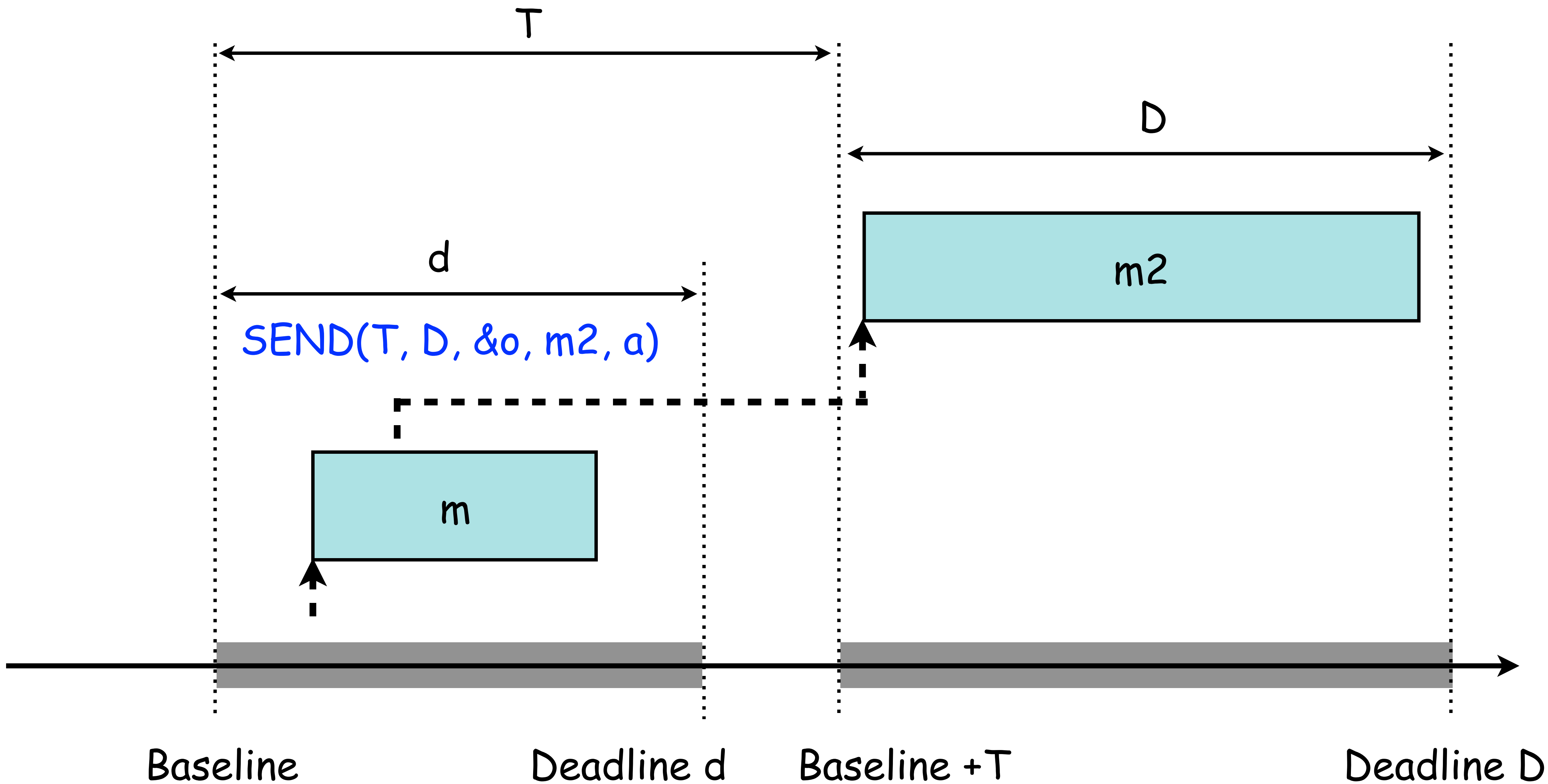
Timing windows



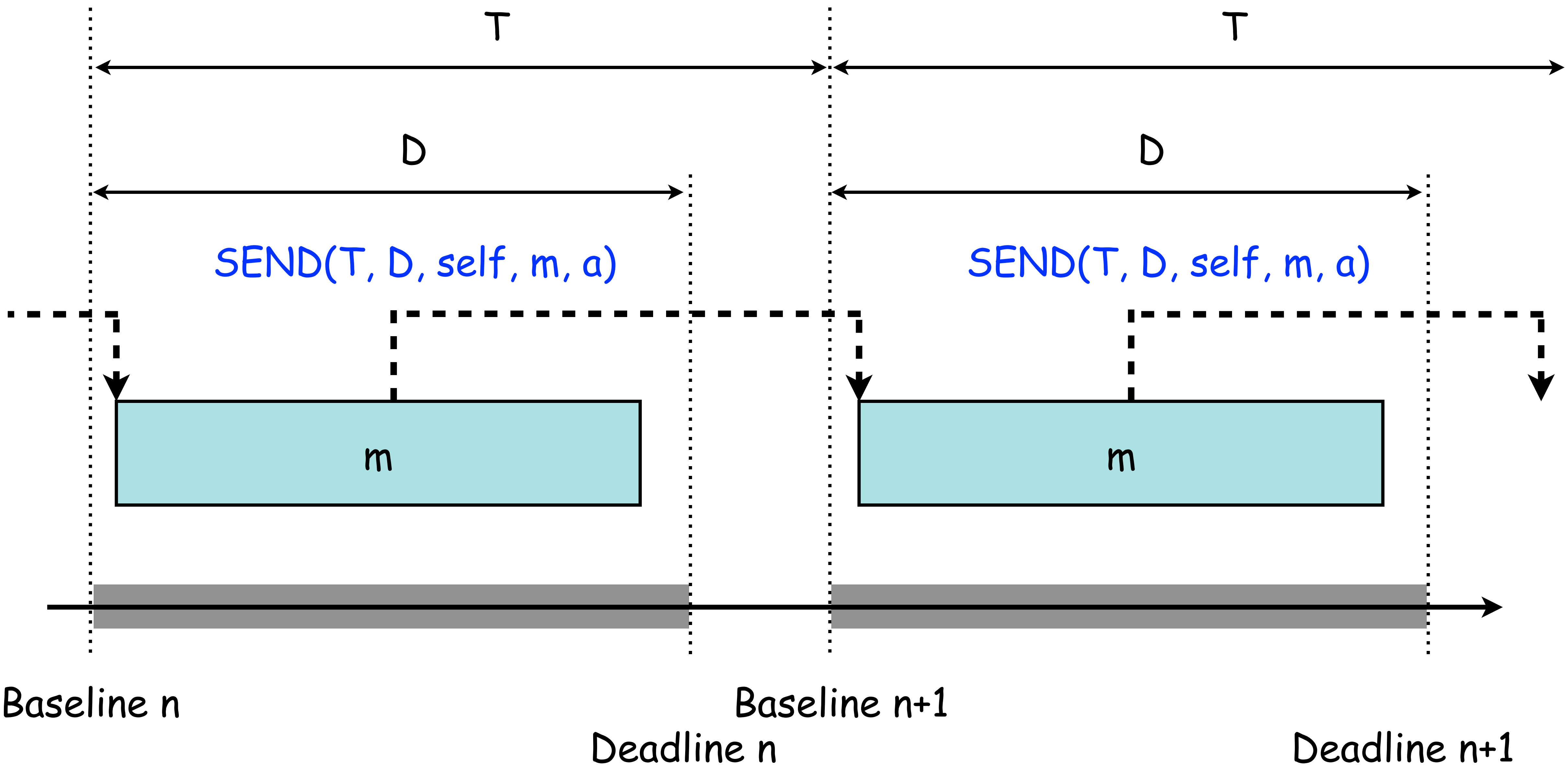
Window resize



Window move


T
D
d
m2
SEND(T, D, &o, m2, a)
m
Baseline
Deadline d
Baseline +T
Deadline D

Constrained periodicity



A clock

```
typedef struct {
    Object super;
    int sec, min, hour;
} Clock;

#define initClock()   { initObject(), 0, 0, 0 }

int tick( Clock *self, int arg ) {
    self->sec++;
    if (self->sec == 60) { self->sec = 0; self->min++; }
    if (self->min == 60) { self->min = 0; self->hour++; }
    AFTER( SEC(1), self, tick, 0 )
}

int sample( Clock *self, CalendarTime *arg ) {
    arg->sec = self->sec; arg->min = self->min; arg->hour = self->hour;
}
```

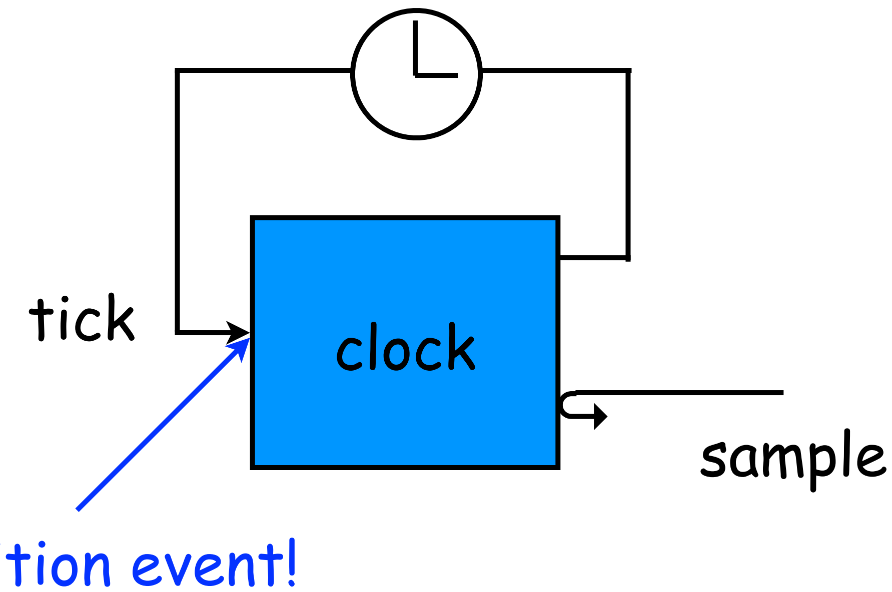
```
typedef struct {
    int sec, min, hour;
} CalendarTime;
```

Use pointer to circumvent one-arg-only restriction.
(Only safe with SYNC)

A clock

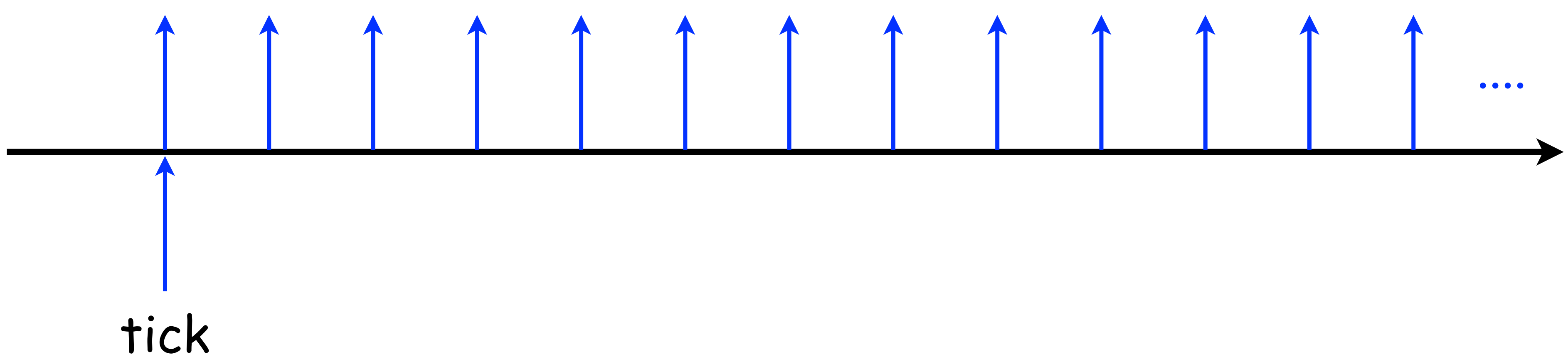
Clock clock = initClock();

Q: Will the clock start oscillating ···· by itself?



TINYTIMBER(&clock, tick, 0);

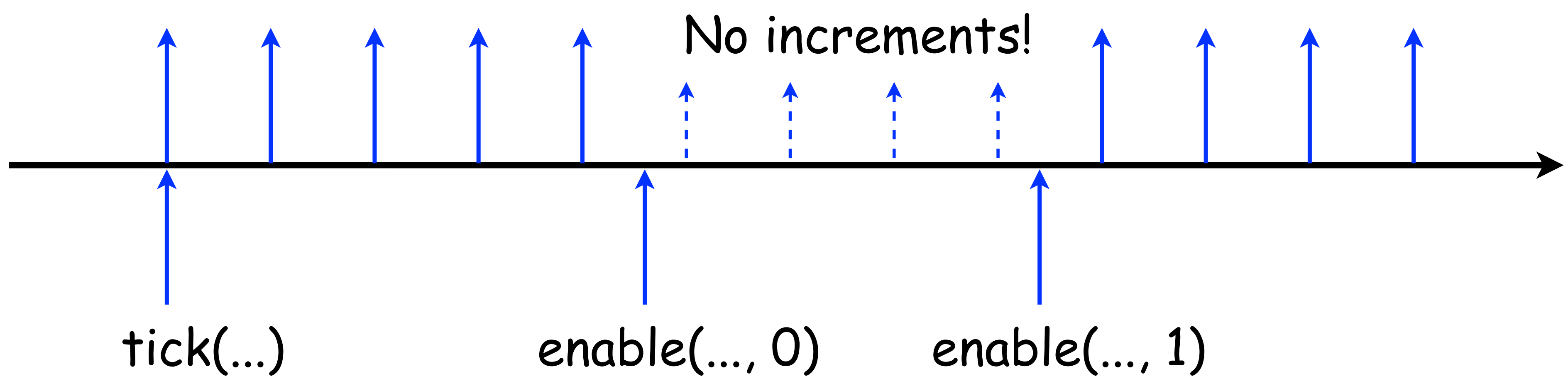
A: No...



An on-off clock

```
typedef struct {
    Object super;
    int sec;
    int enabled;
} OnOffClock;

#define initOnOffClock()    { initObject(), 0, 1 }

int tick( OnOffClock *self, int arg ) {
    if (self->enabled)
        self->sec = self->sec + 1;
    AFTER( SEC(1), self, tick, 0 )
}

int sample( OnOffClock *self, int arg ) {   return self->sec;   }

int enable( OnOffClock *self, int en ) {   self->enabled = en;   }
```

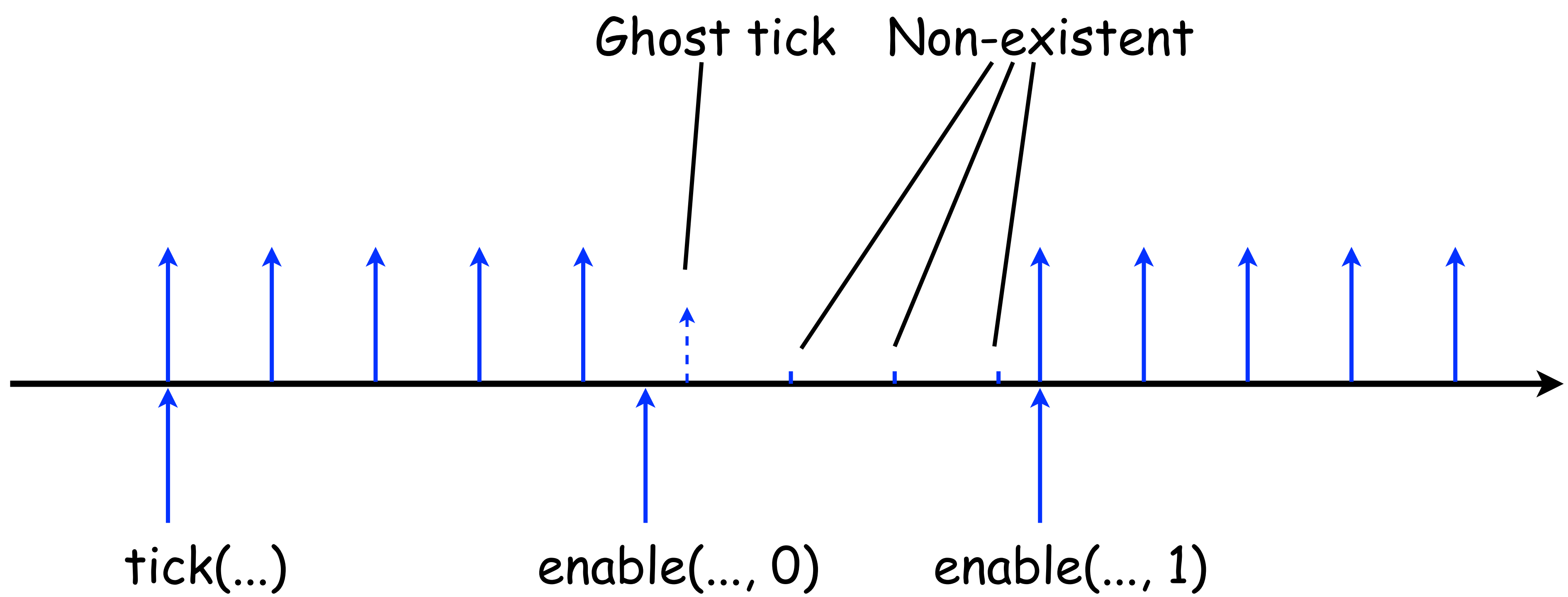
An on-off clock



A different on-off clock

```
typedef struct {
    Object super;
    int sec, enabled;
} OnOffClock2;

#define initOnOffClock2()   { initObject(), 0, 1 }

int tick( OnOffClock2 *self, int arg ) {
    if (self->enabled) {
        self->val = self->val + 1;
        AFTER( SEC(1), self, tick, 0 )
    }
}

int sample( OnOffClock2 *self, int arg ) {   return self->sec;   }

int enable( OnOffClock2 *self, int en ) {
    if (en && !self->enabled)   ASYNC( self, tick, 0 );
    self->enabled = en;
}
```

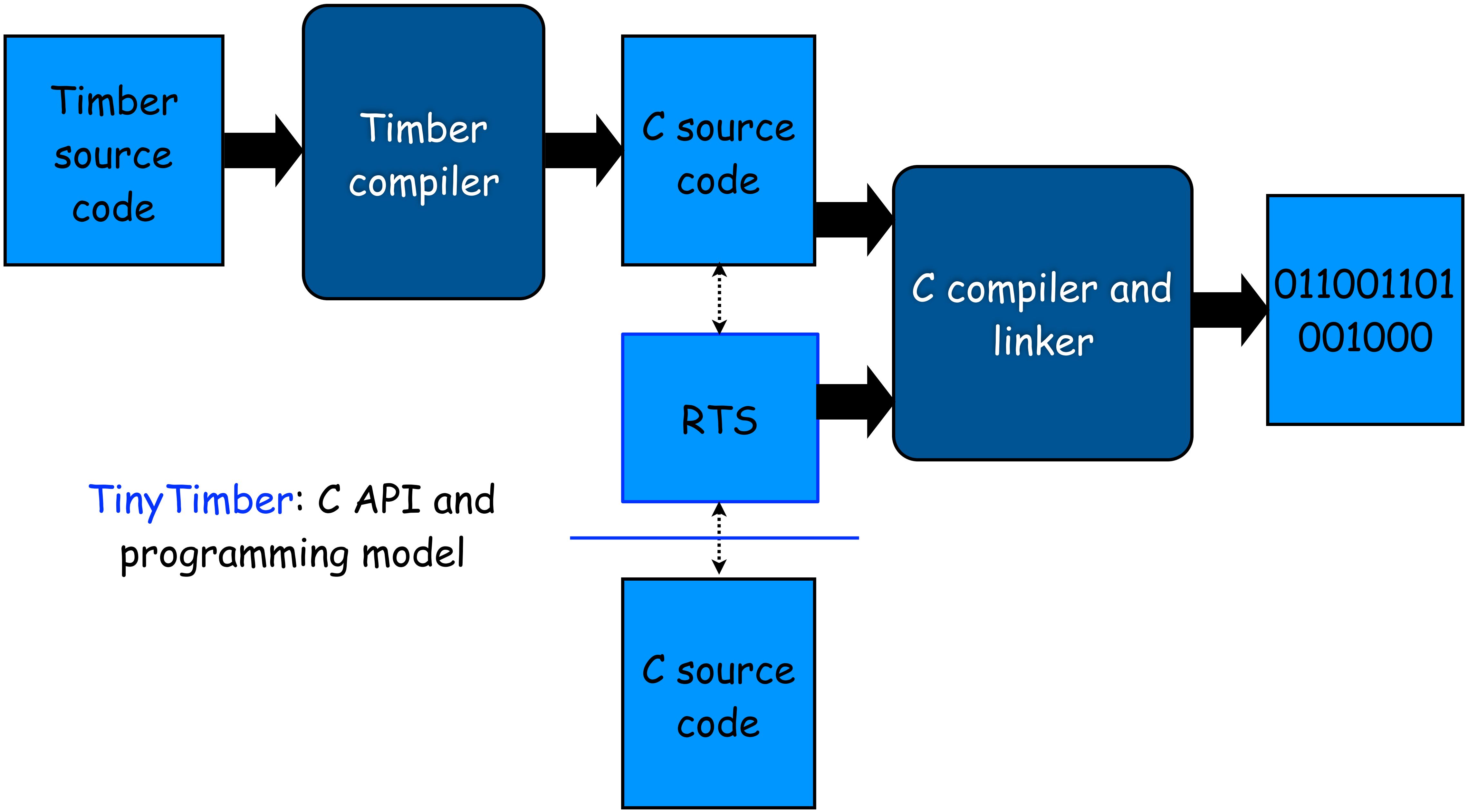
A different on-off clock



Timber

- The big brother of TinyTimber
- Full-featured language:
  - Higher-order & strongly typed
  - Dynamic object creation, garbage-collected heap
  - Haskell-like syntax (but no laziness!)
  - Purely functional computation sub-language
- A real-time successor to O'Haskell (an OO Haskell ext.)
- Developed in part by groups & individuals at Chalmers, Luleå U. of T., Oregon Grad. Inst., Kansas State U.

Compiling Timber



Wrapping up

TinyTimber offers:

- Lightweight real-time facilities for C
- Implicit concurrency
- Implicit state protection
- Object-oriented program structure
- Robust timing semantics

Main conceptual treshold for programmers: Reactivity!

The big win of reactivity:

Modular composition of real-time systems
with composable timing!