Token Machine Language (TML):
An Intermediate Language for Sensor Networks

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High Level Languages

Middleware

Node-level runtime

High Level Languages

Data parallel langs

Query Langs (Cougar, TinyDb)

Regiment

Spatial Views, EIP

Rule-based langs

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Neighborhood mgmt

Localization

Heartbeats

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TinyOS/NesC

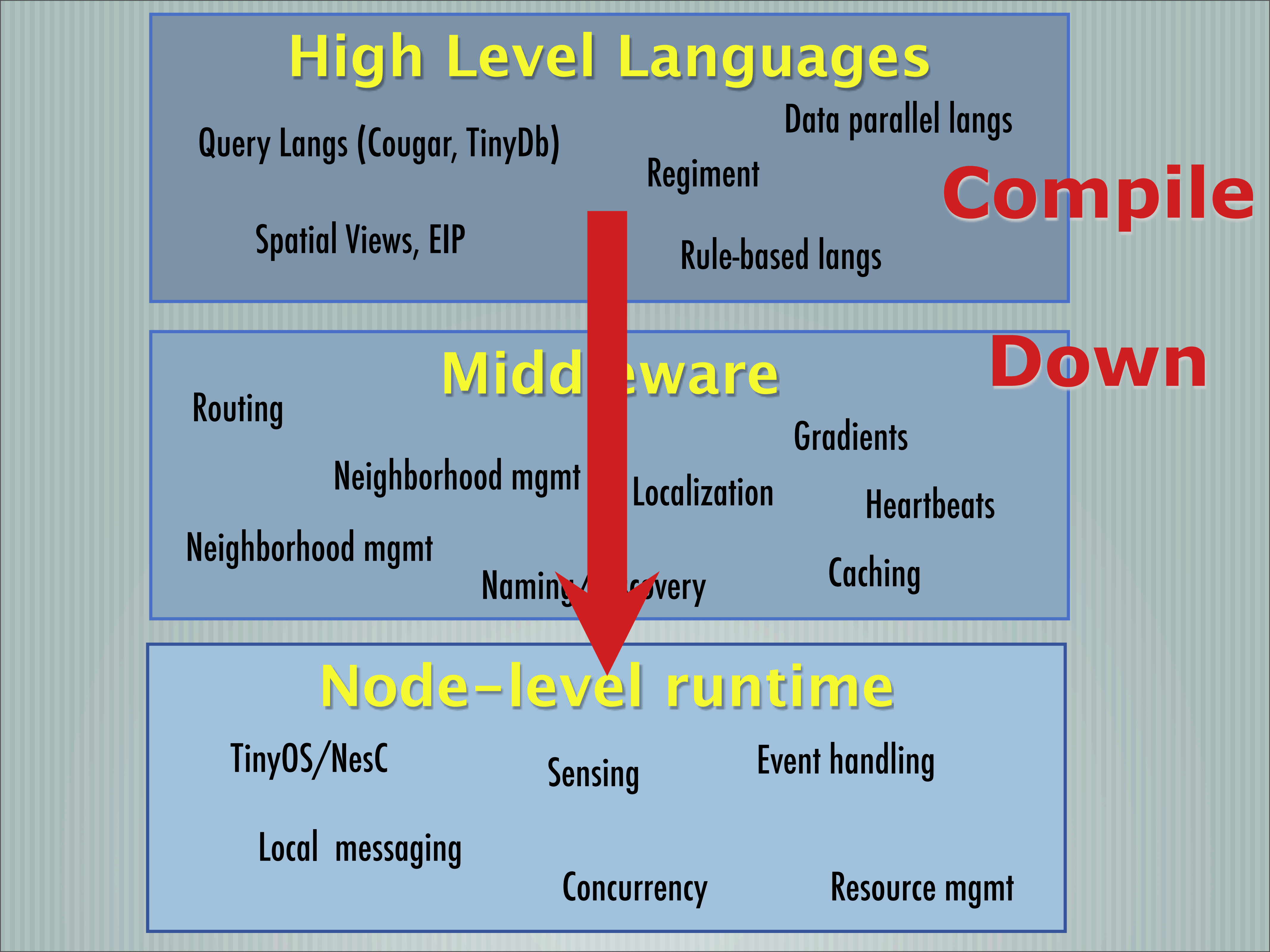
Sensing

Event handling

Local messaging

Concurrency

Resource mgmt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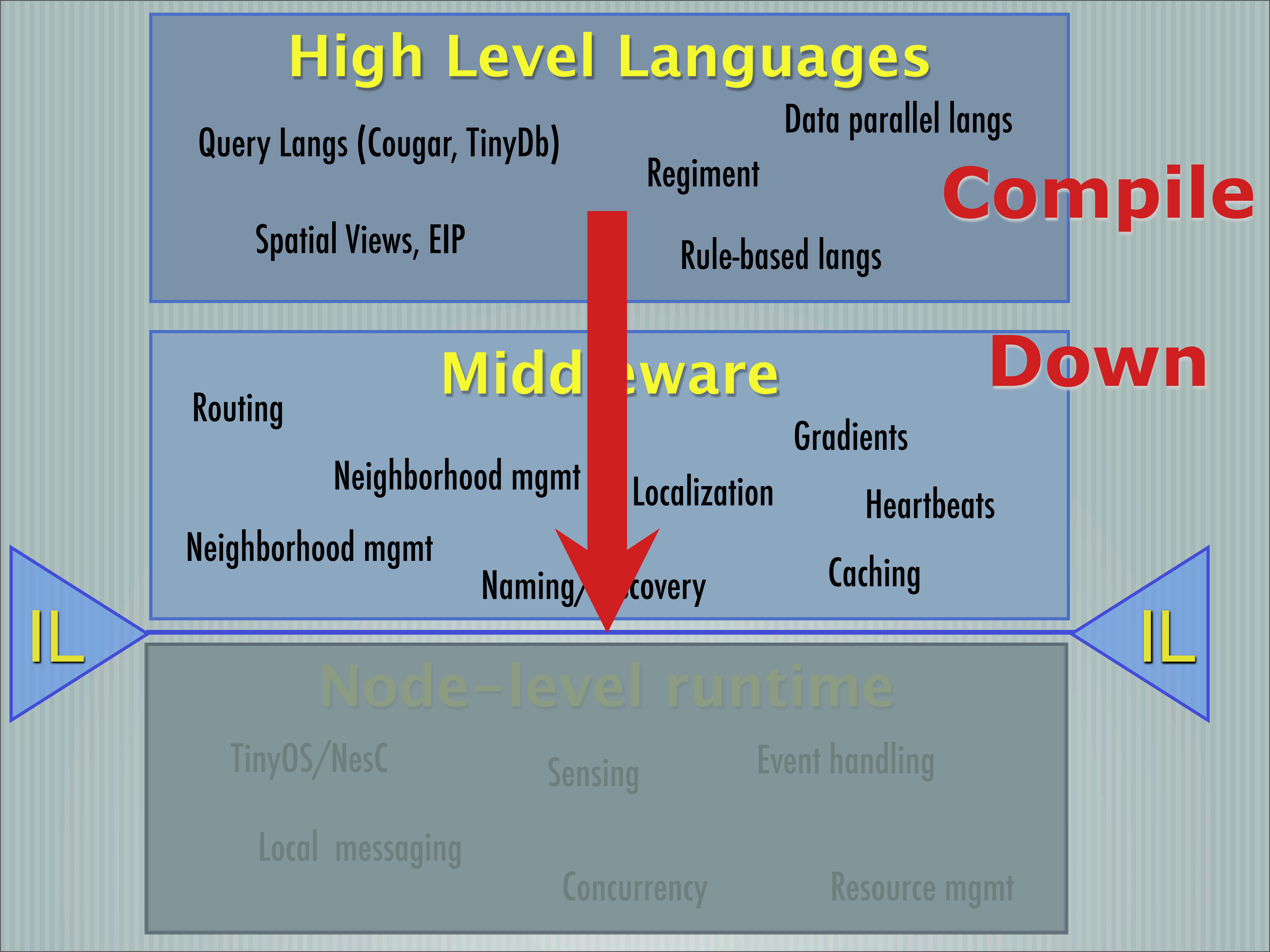
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Question

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- Can an intermediate language for sensor networks

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- fit Tiny architectures

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- fit Tiny architectures
- be conducive to building higher abstractions

  (expressive, extensible)

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Can an intermediate language for sensor networks

- fit Tiny architectures
- be conducive to building higher abstractions

  (expressive, extensible)
- be semantically *simple* and easy to reason about

Potential models for computation

	Tiny?	Rich/ Extensible?	Clean, Simple Model?
TinyOS/NesC	T	T	?
TinyDB	T	?	T
JVM	?	T	T

Our approach: token machines

- Atomic actions
- Unified control, communication, and storage model (tokens)
- Simple and lightweight model

Token Machine Model

TM Model

TM Model : concurrency

```
{
    ...
}
```

TM Model : concurrency

Atomic Blocks

```
{
    ...
}
```

TM Model : concurrency

Atomic Blocks

```
{
   if (...)
   {...}
}
```

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One execution context

TM Model : concurrency

Atomic Blocks

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token T
{
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One execution context

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Atomic Blocks

```
token T
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```
token
{
   if (...)
   {...}
}
```

```
token
{
   if (...)
   {...}
}
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```
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   {...}
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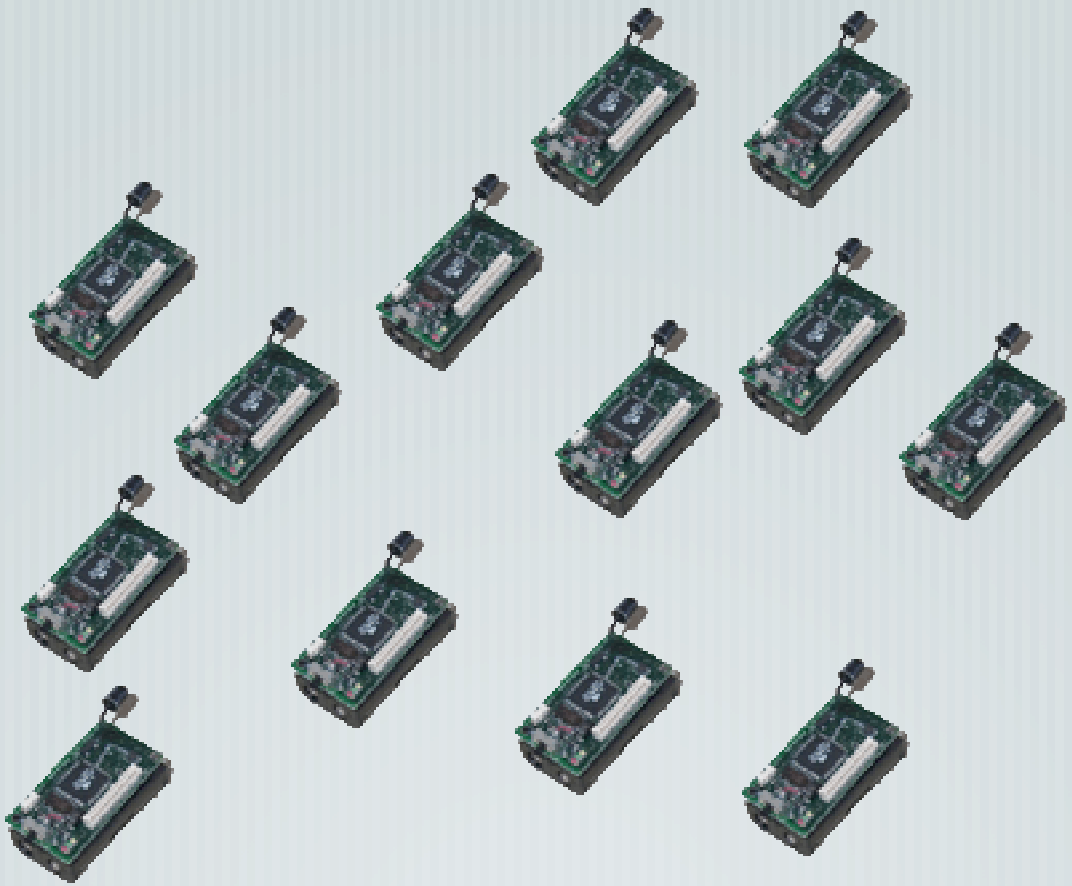
One execution context

TM Model : big picture



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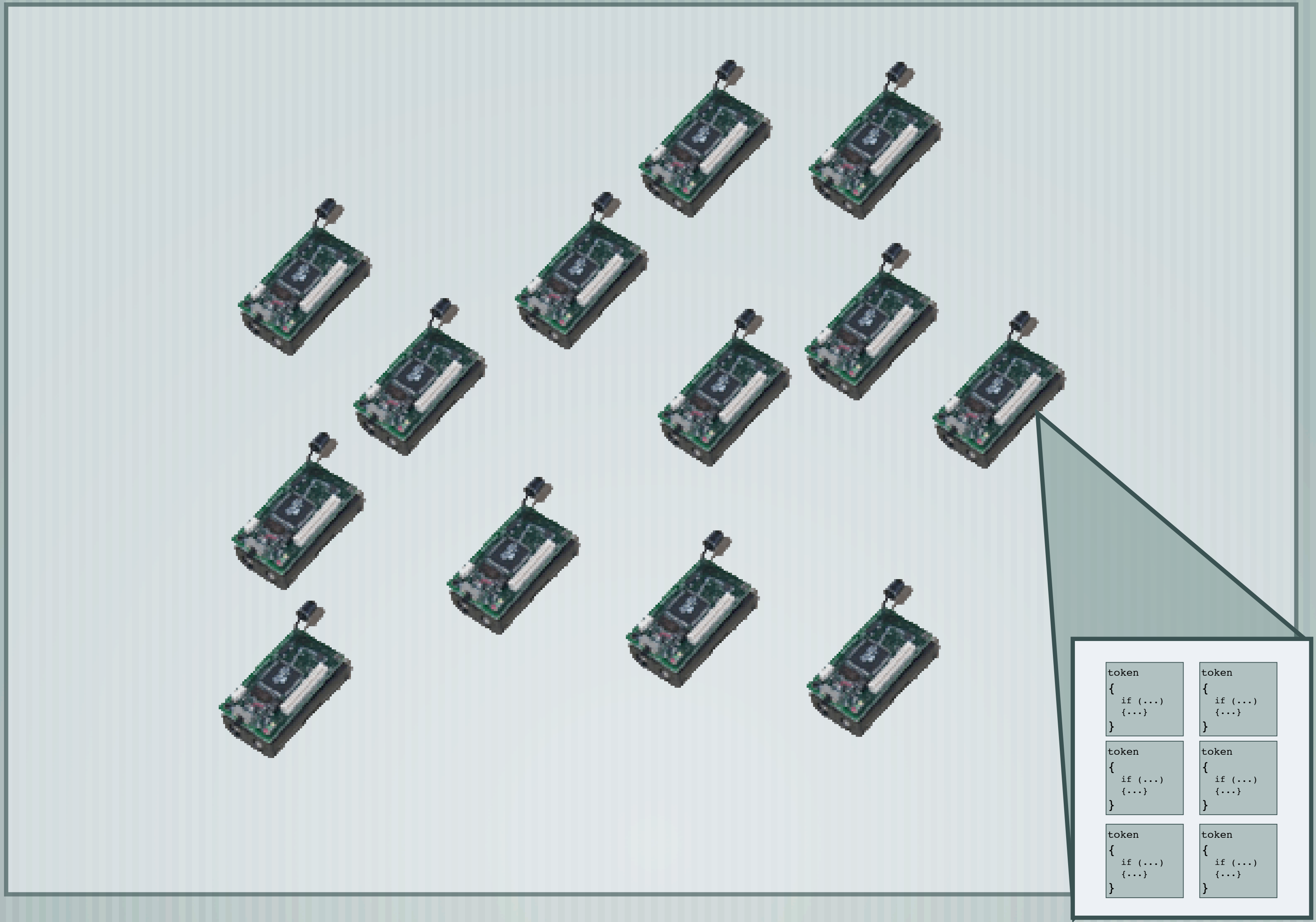

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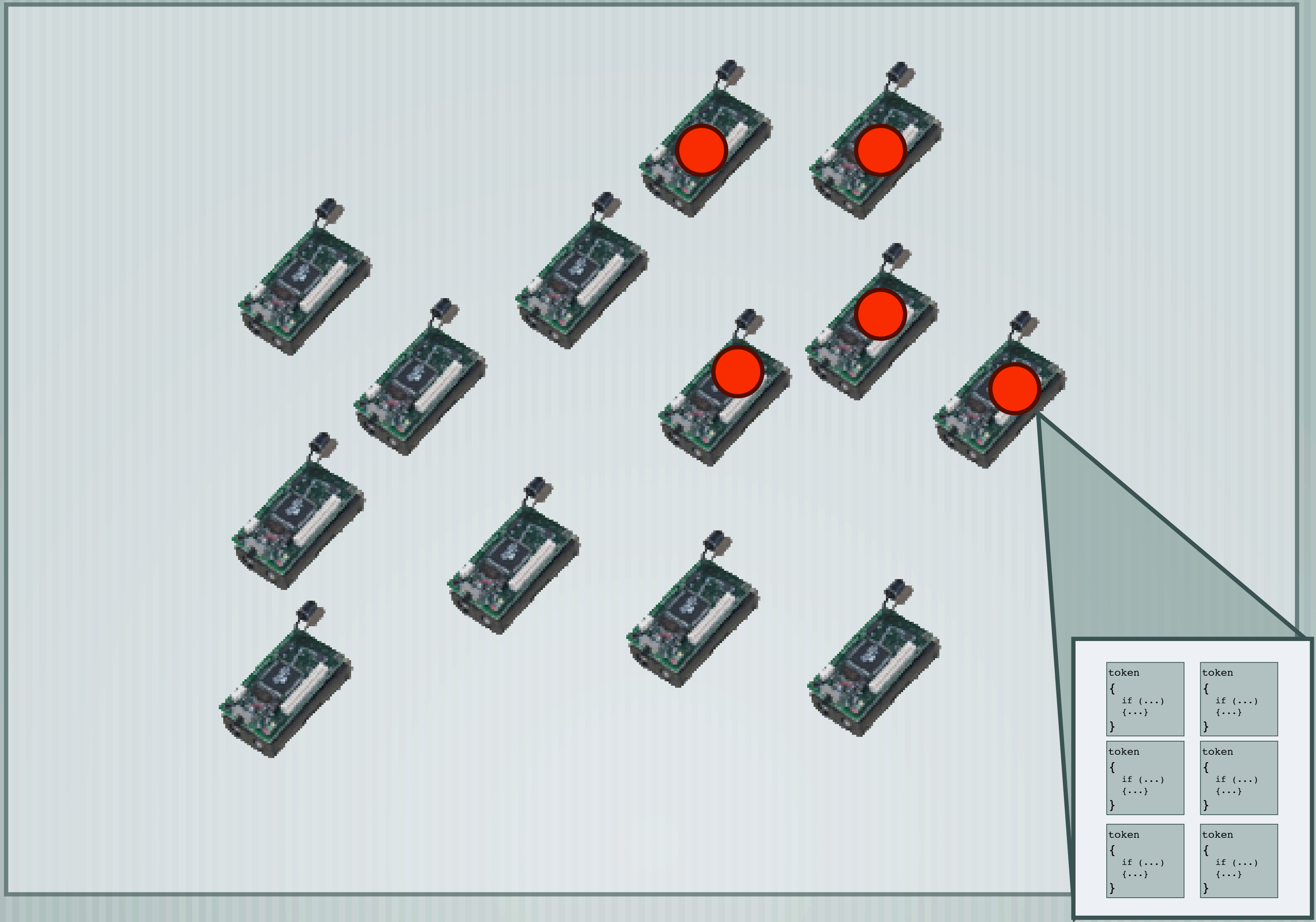

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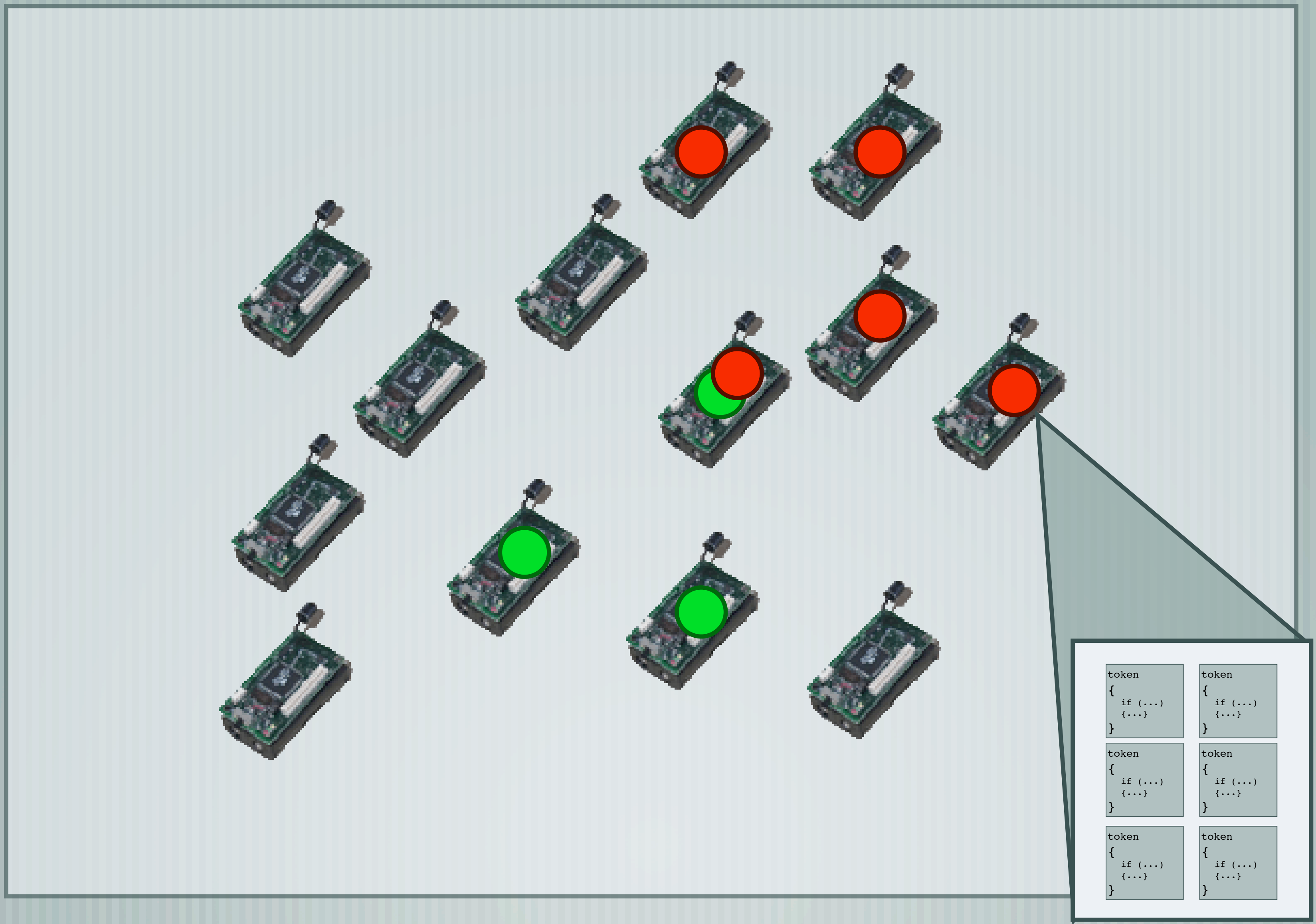

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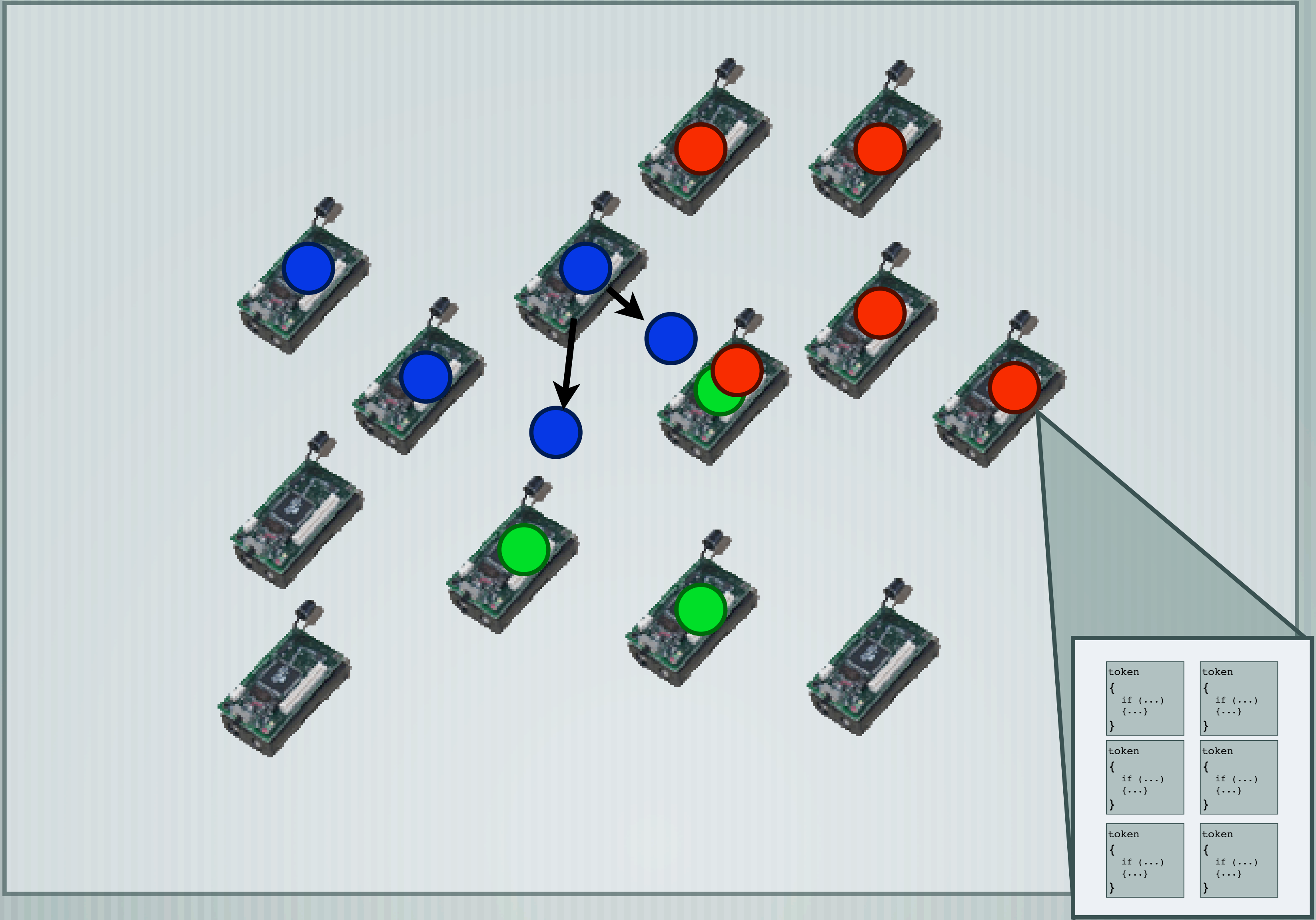
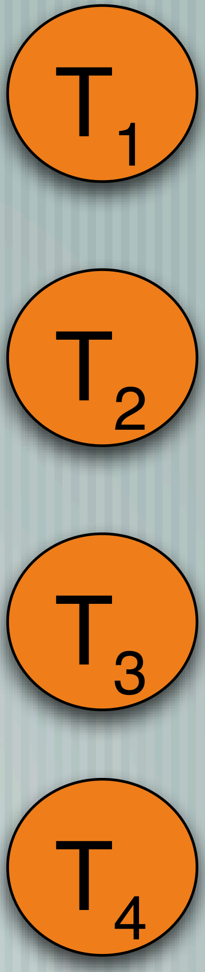


TM Model : tokens

```
token T
{
   if (...)
   {...}
}
```

TM Model : tokens

```
token T1
{
    if (...)
    {...}
}
```



TM Model : tokens

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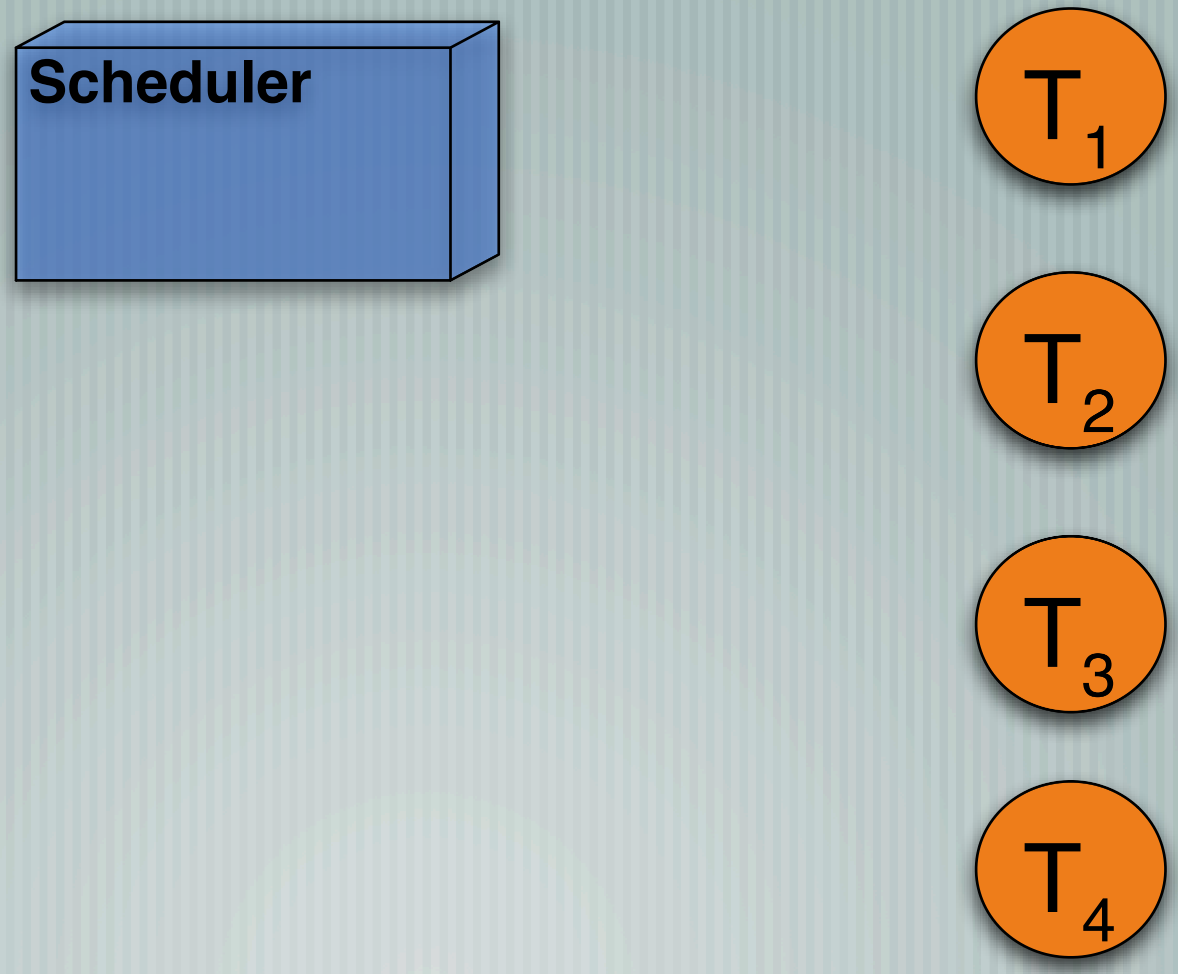

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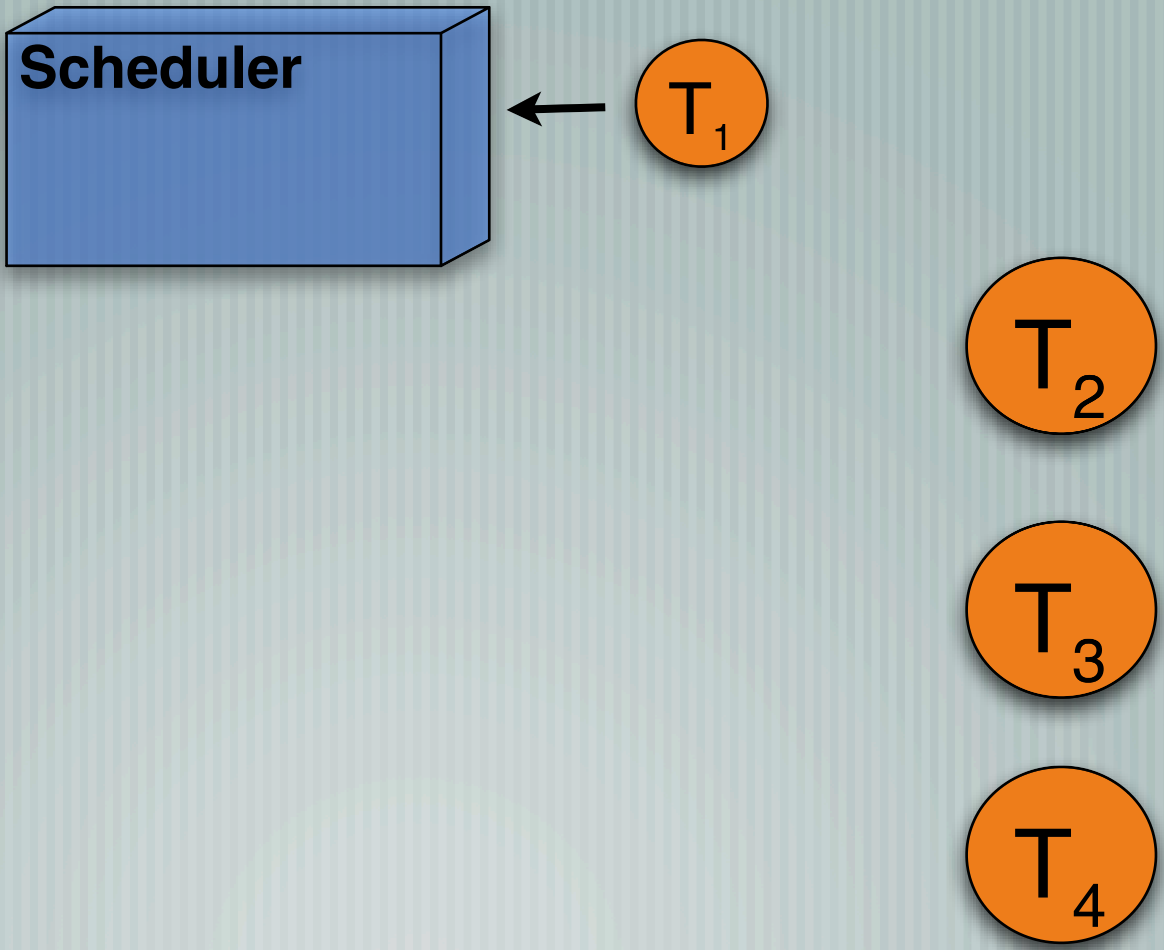
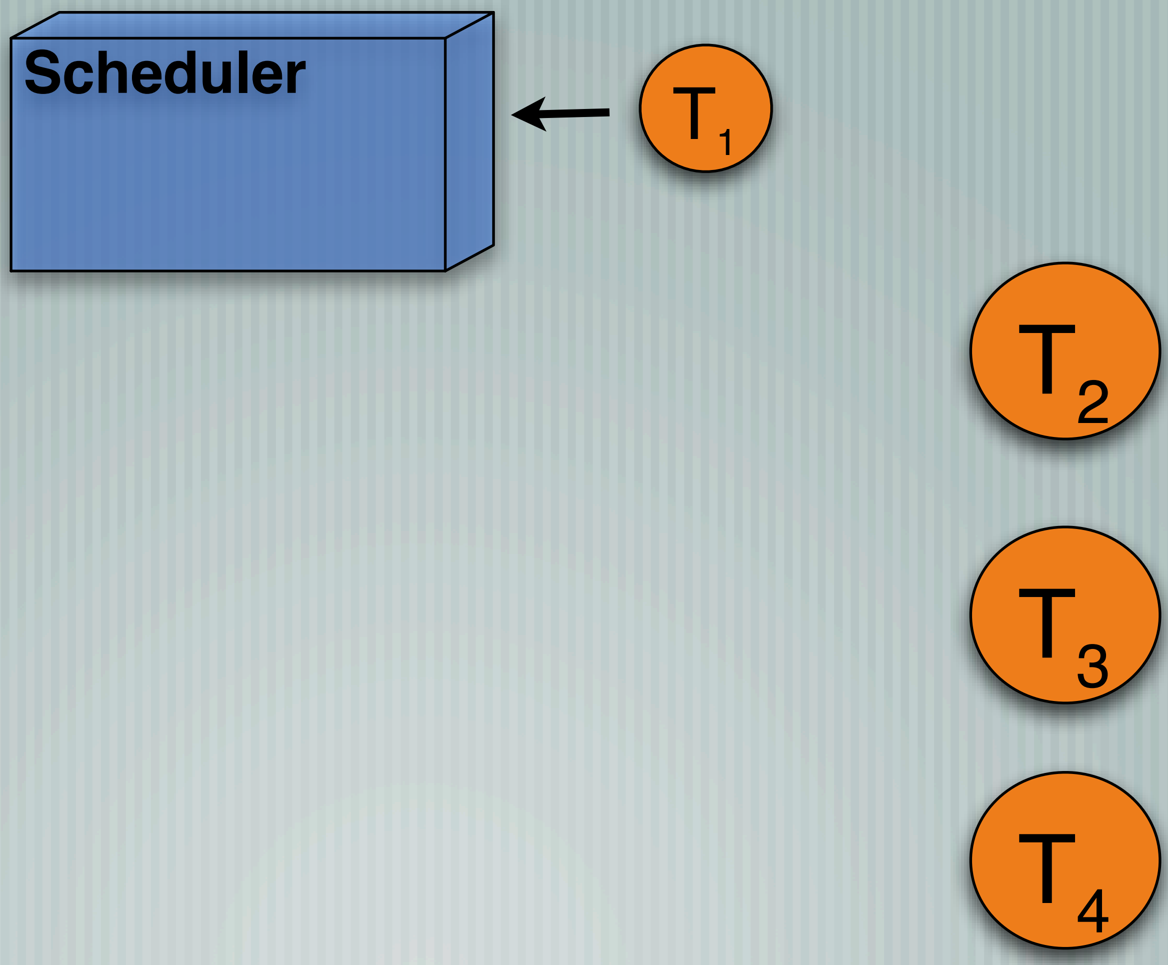


TM Model : tokens

```
token T1(x,y)
{
   if (...)
   {...}
}
```



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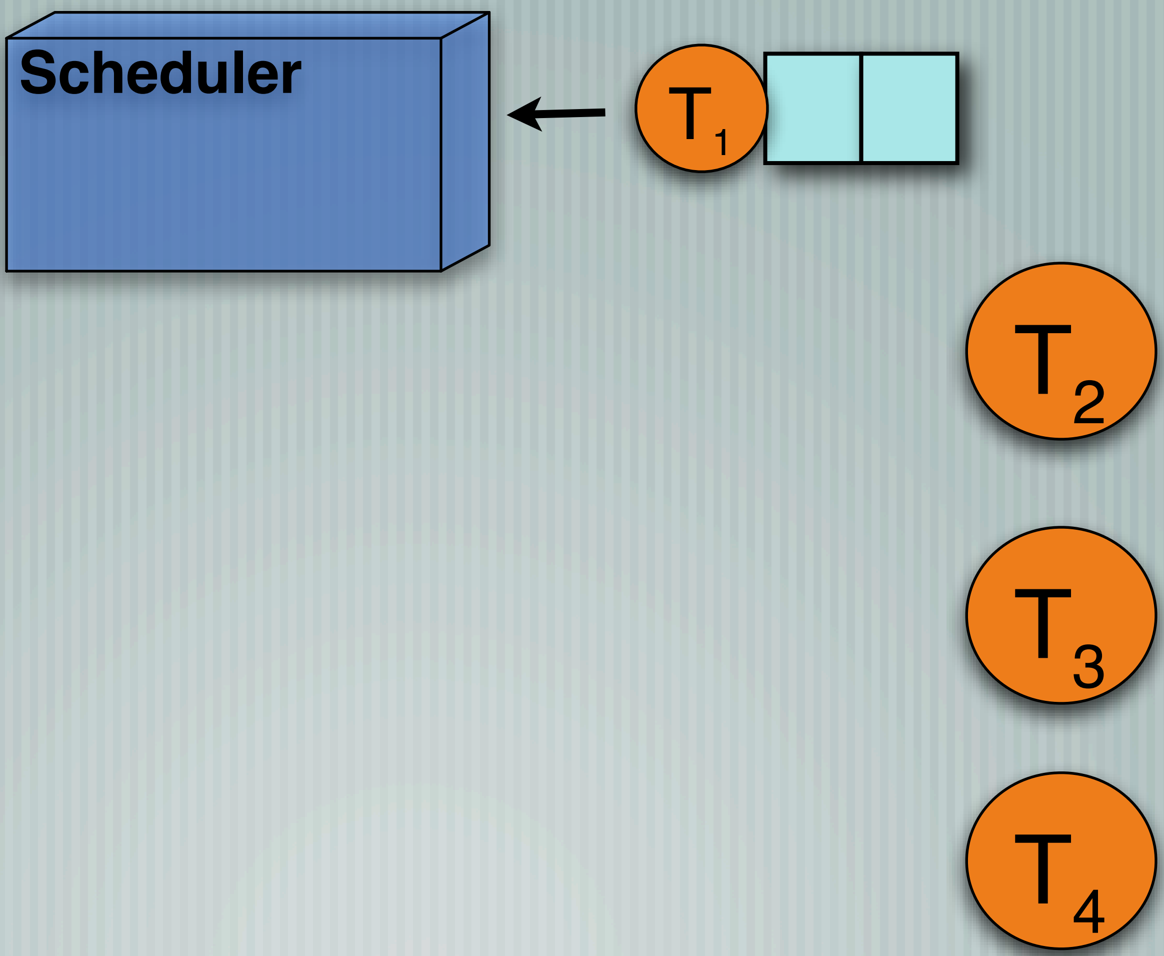


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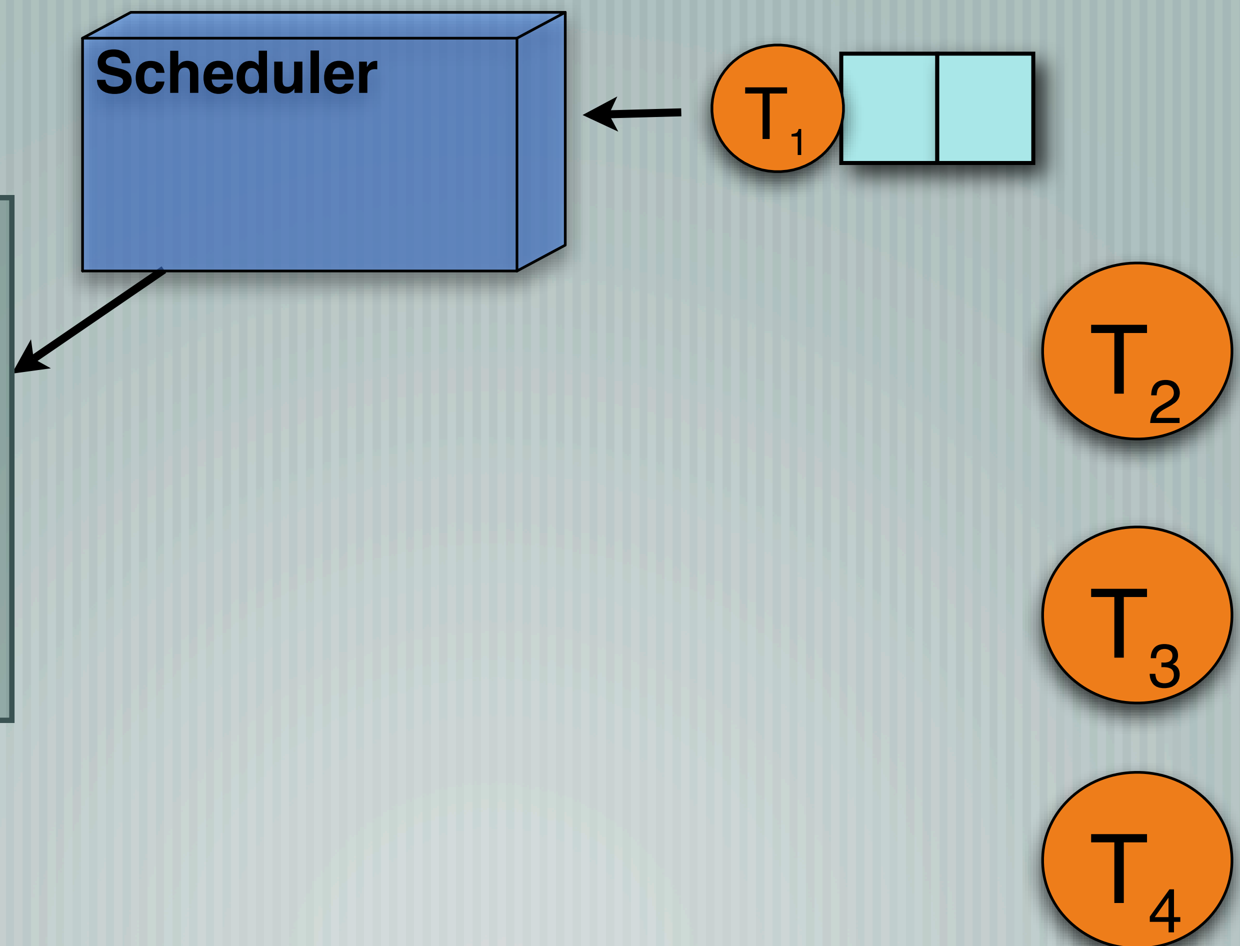


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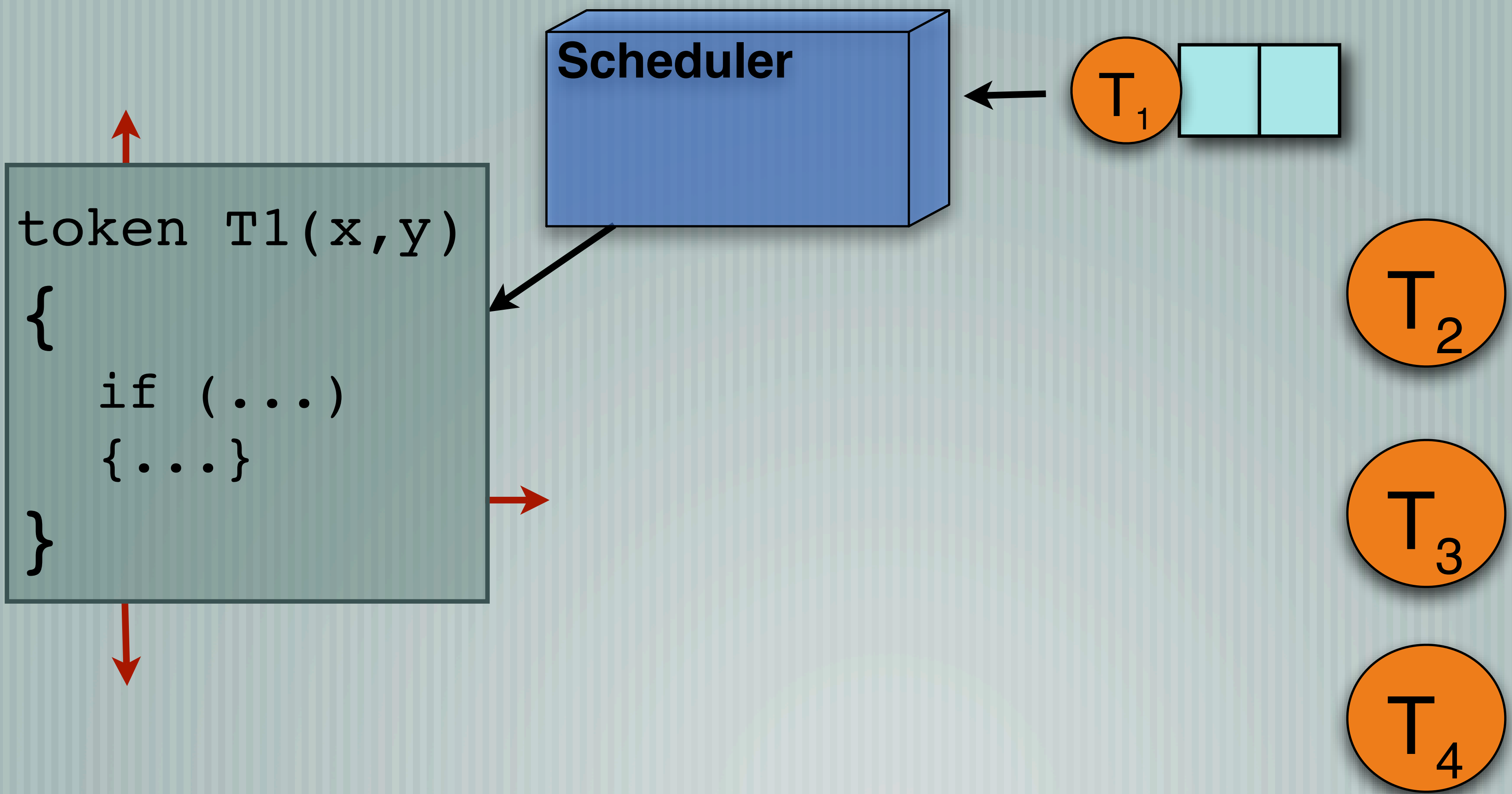

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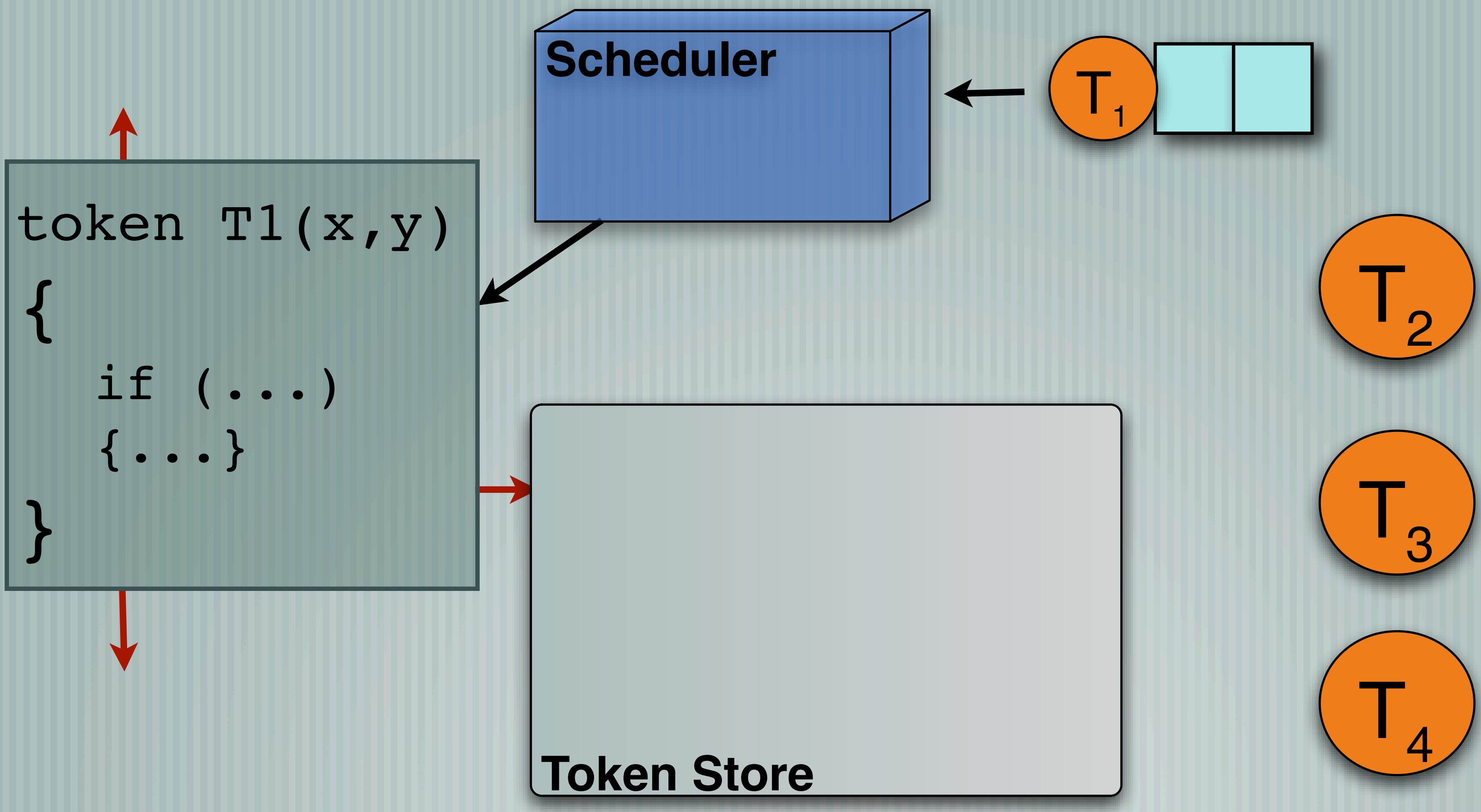

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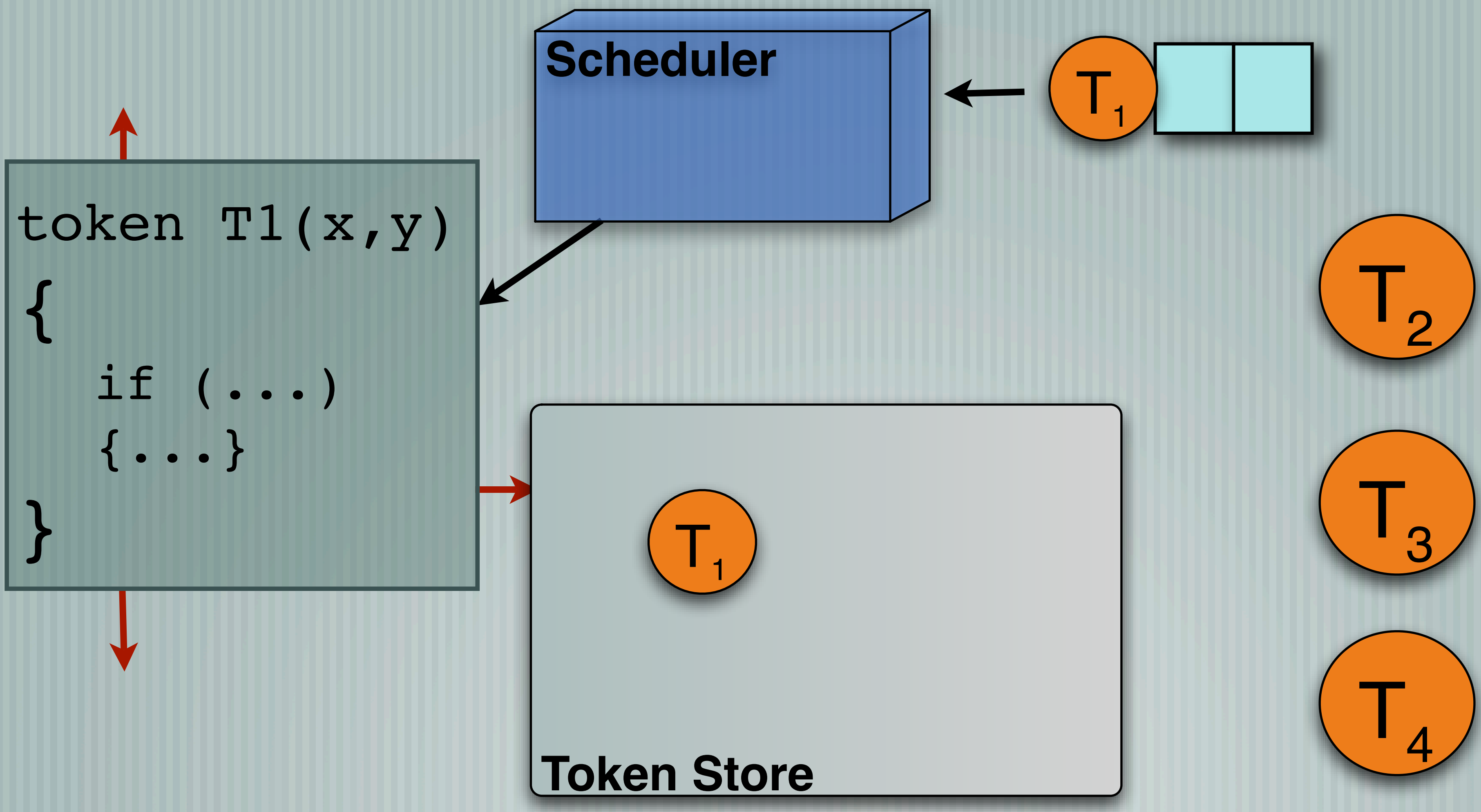

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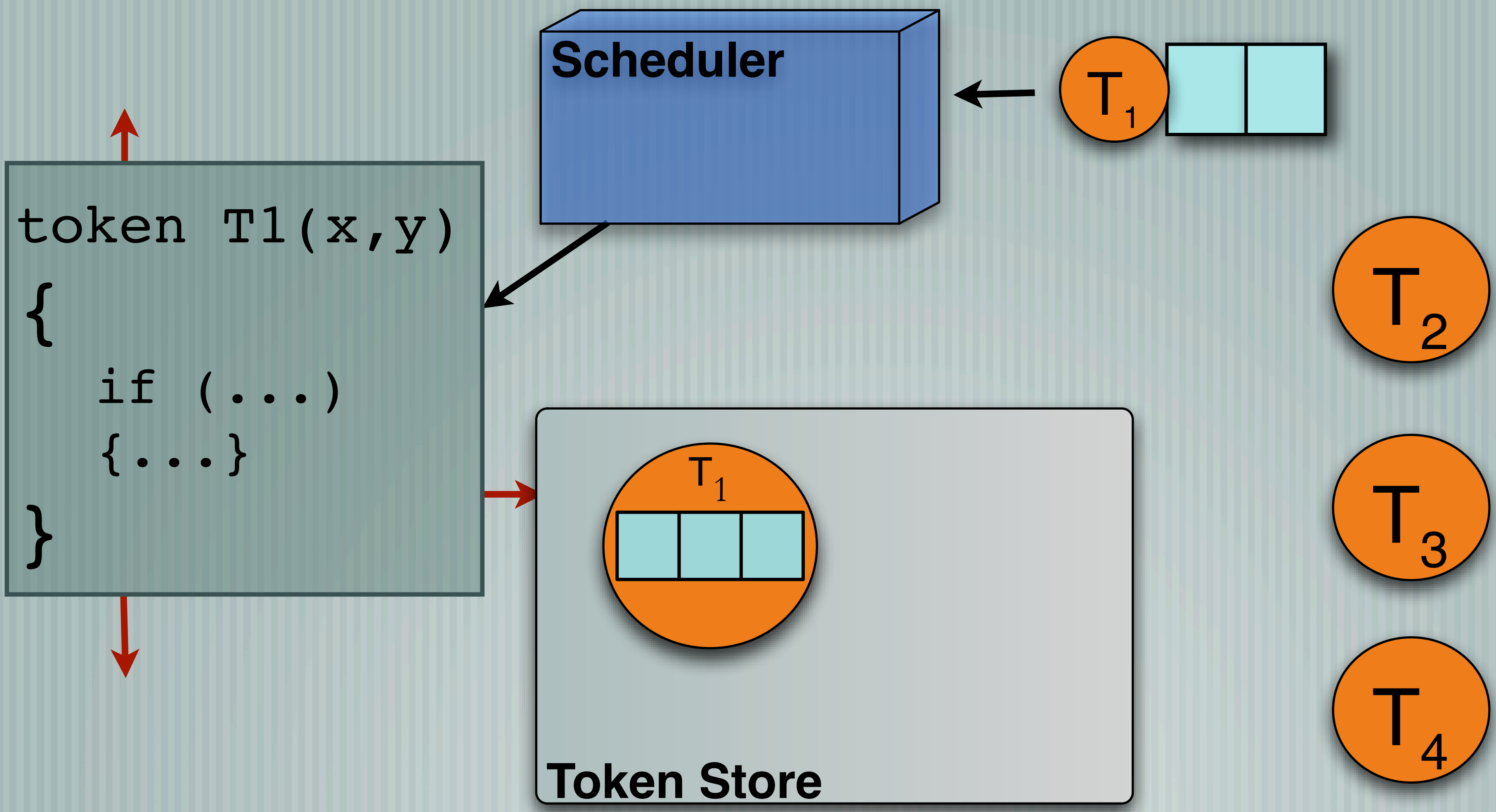

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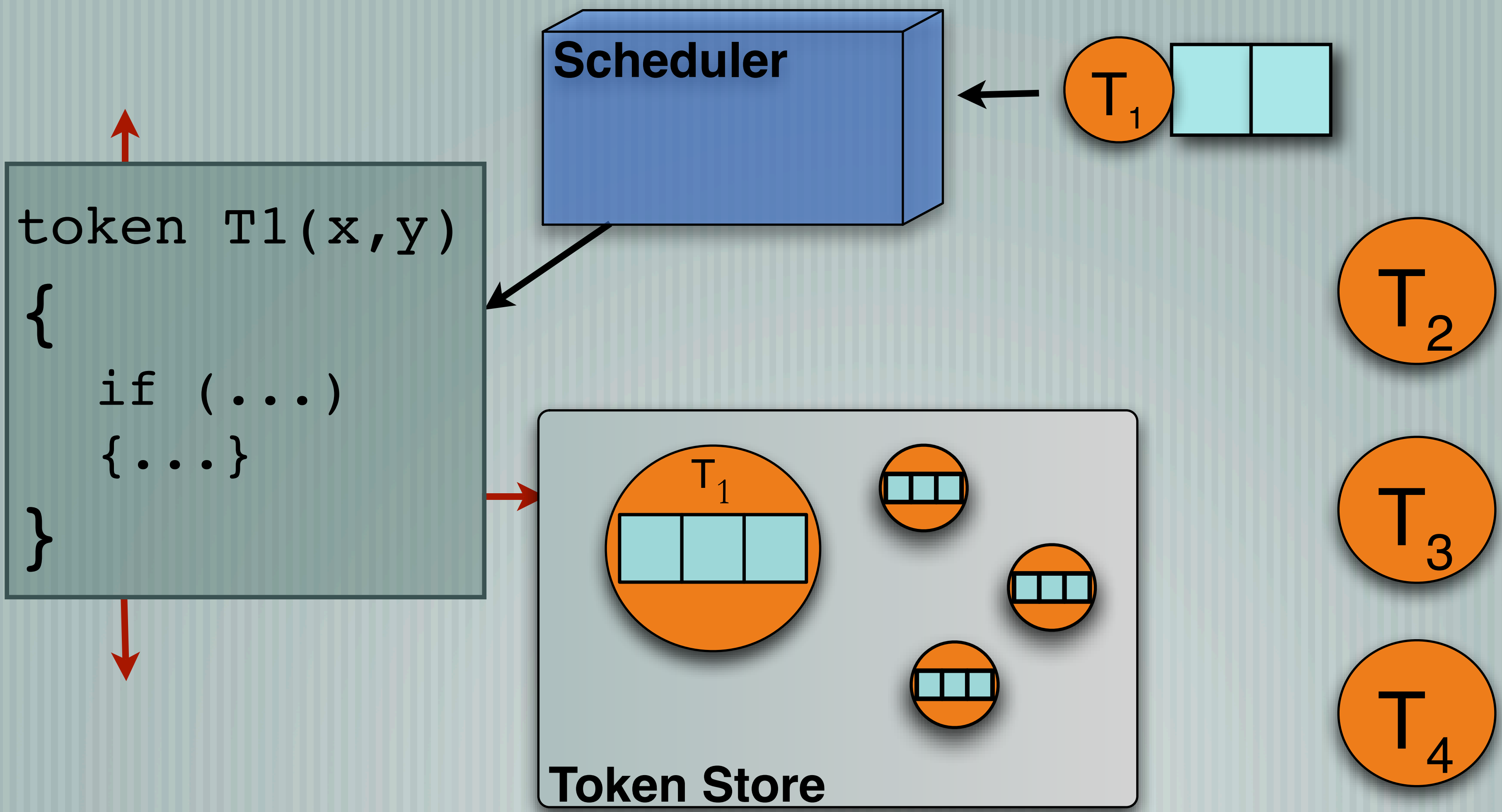

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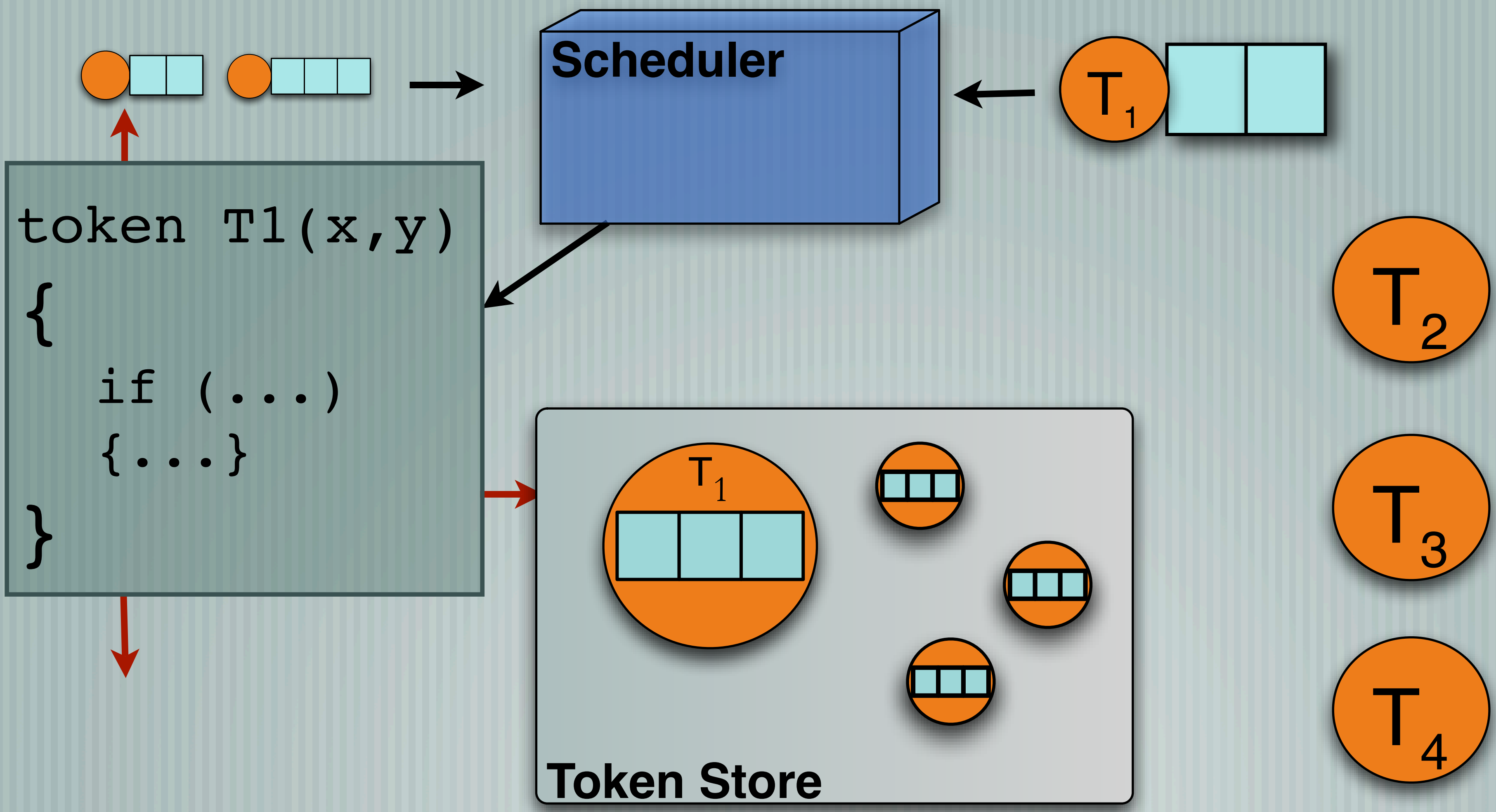

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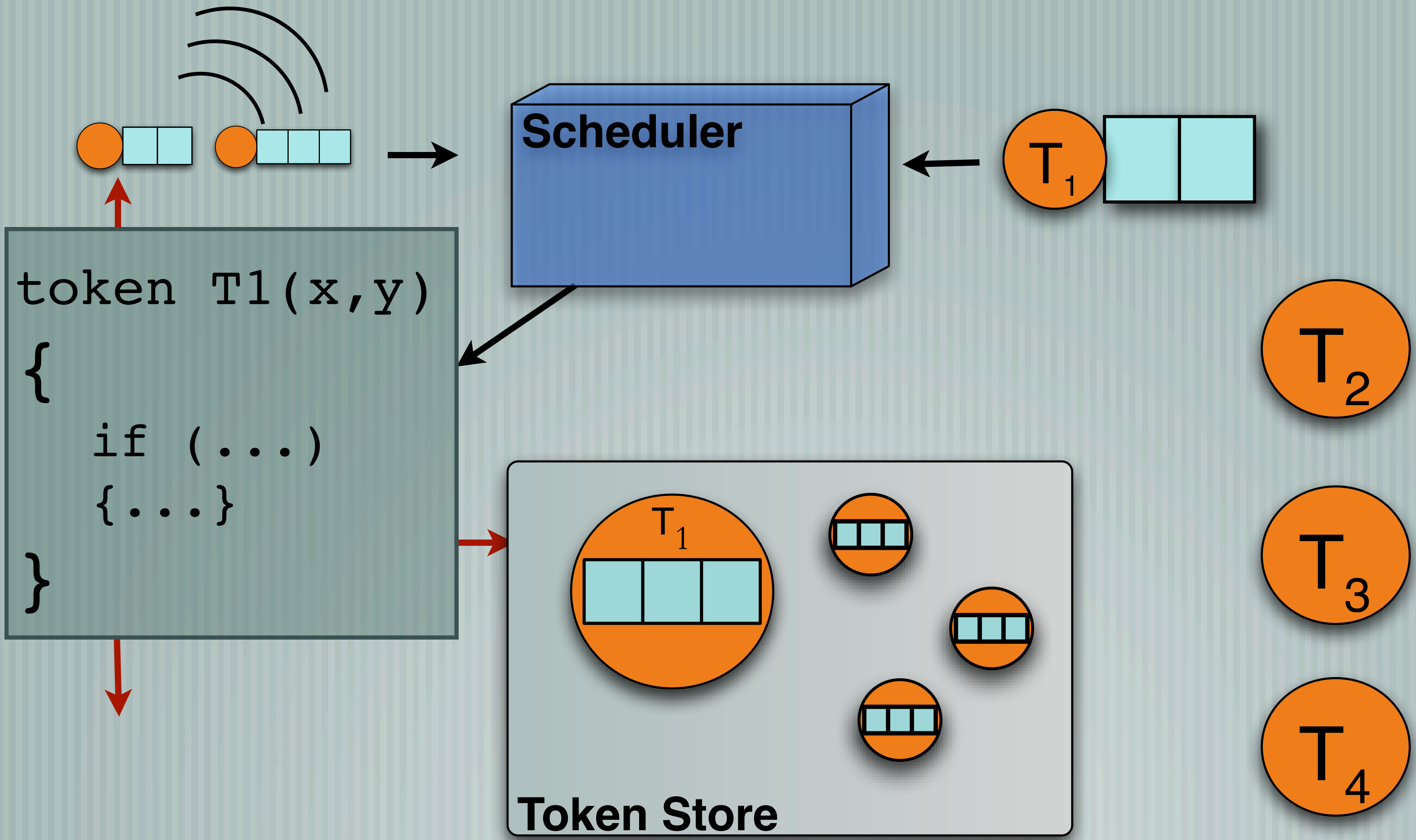

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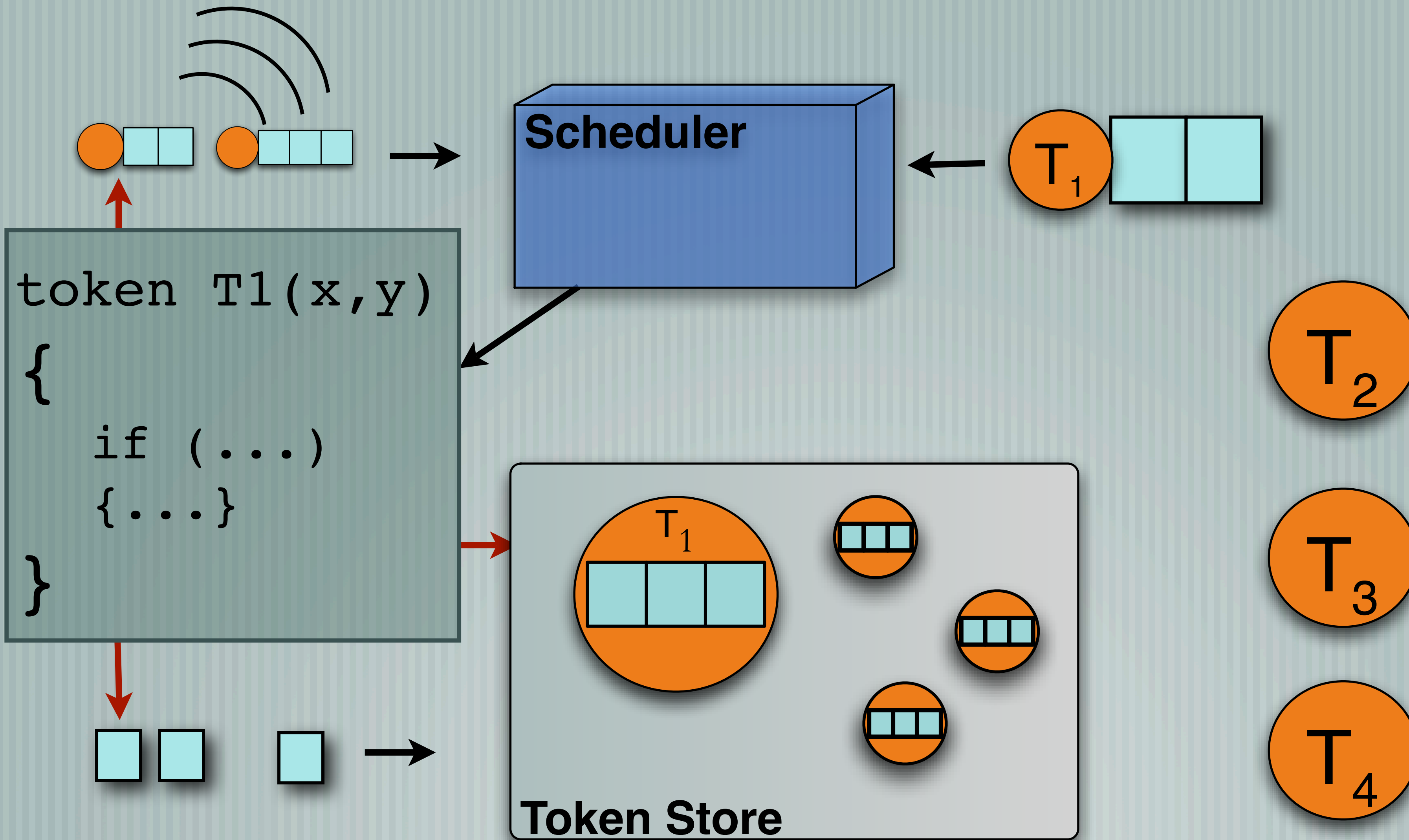
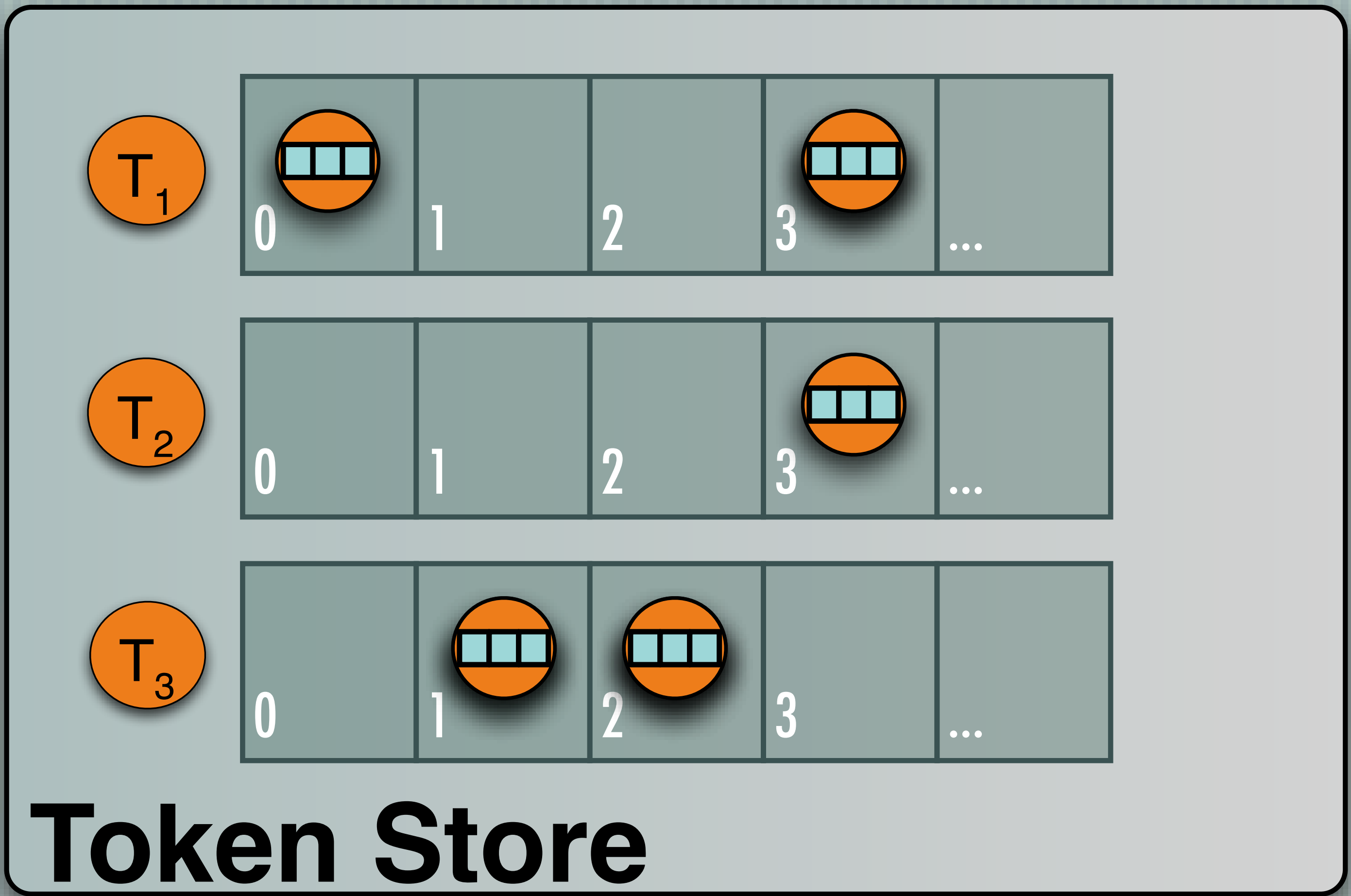
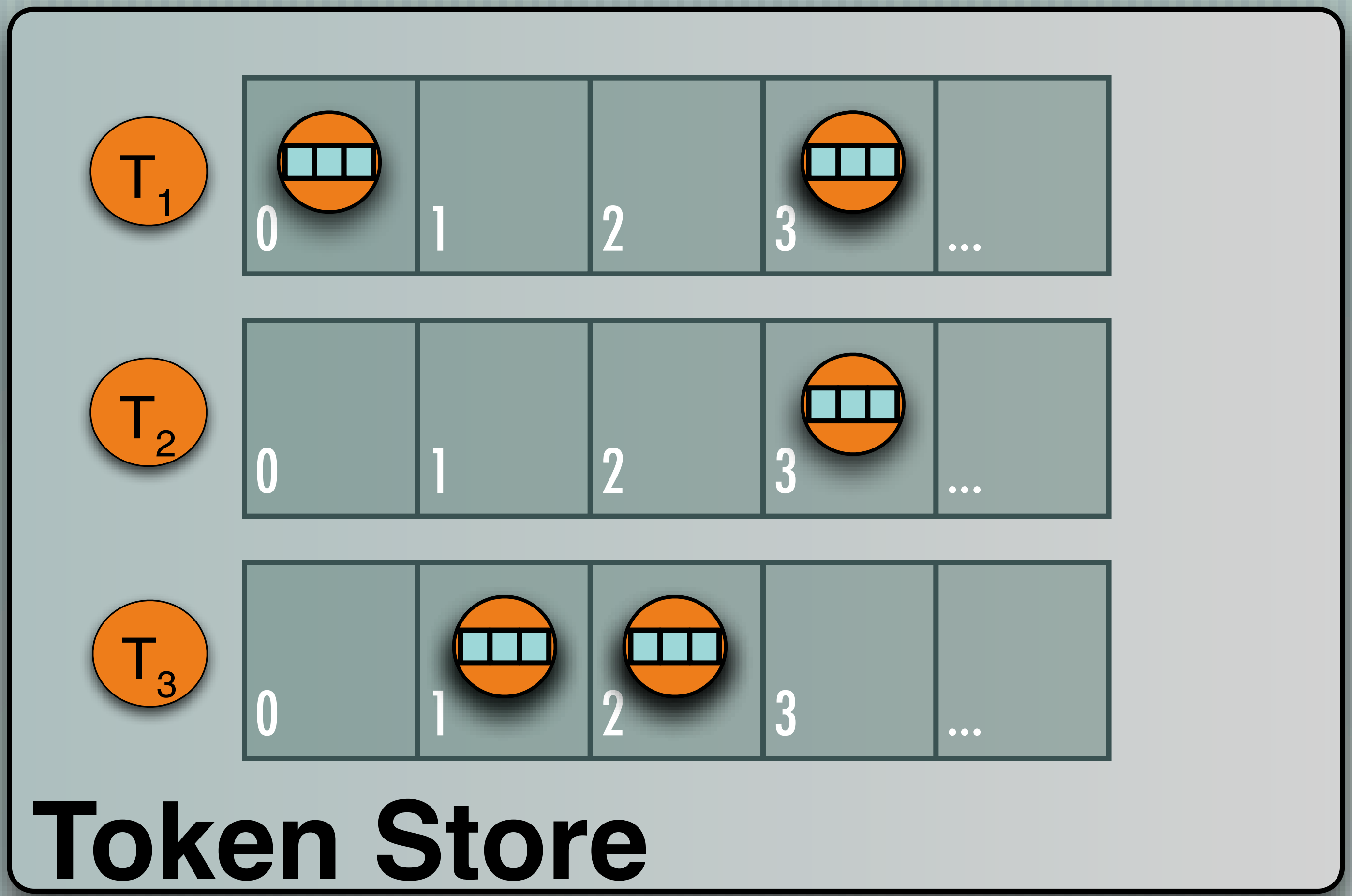


TM Model : memory allocation



TM Model : memory allocation



Consistent Inter-node virtual addresses: $T_2[4]$

Token Store replaces Stack

- `Red, Red[2], Red[7]`
- `call Red[1](x);`
- `(subcall Red[1](x)) + 8;`
  - Uses implicit continuation objects.

User code API

- call
- timed_call
- bcast

- is_scheduled
- deschedule

- is_loaded
- evict

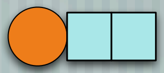
Plus!
- subcall

Token-unified framework

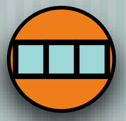
- Concurrency: atomic token handlers

```
token
{
  if (...)
  {...}
}
```

- Communication: token messages
  - both local and remote messaging



- Memory: token objects on heap
  - subtokens allow for dynamic allocation

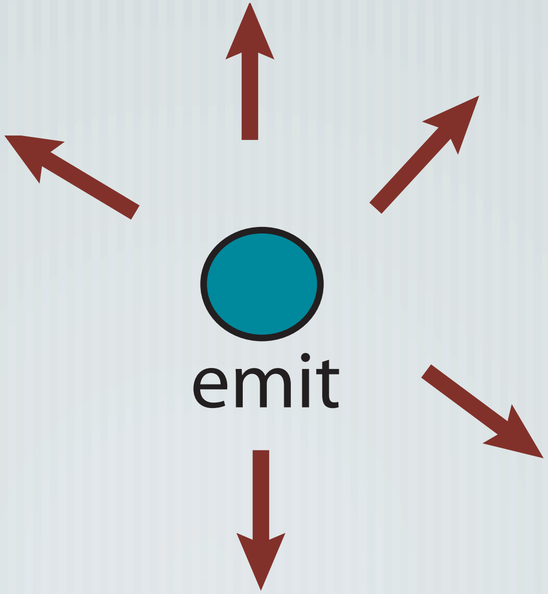


Building on TML

Gradients

Gradients

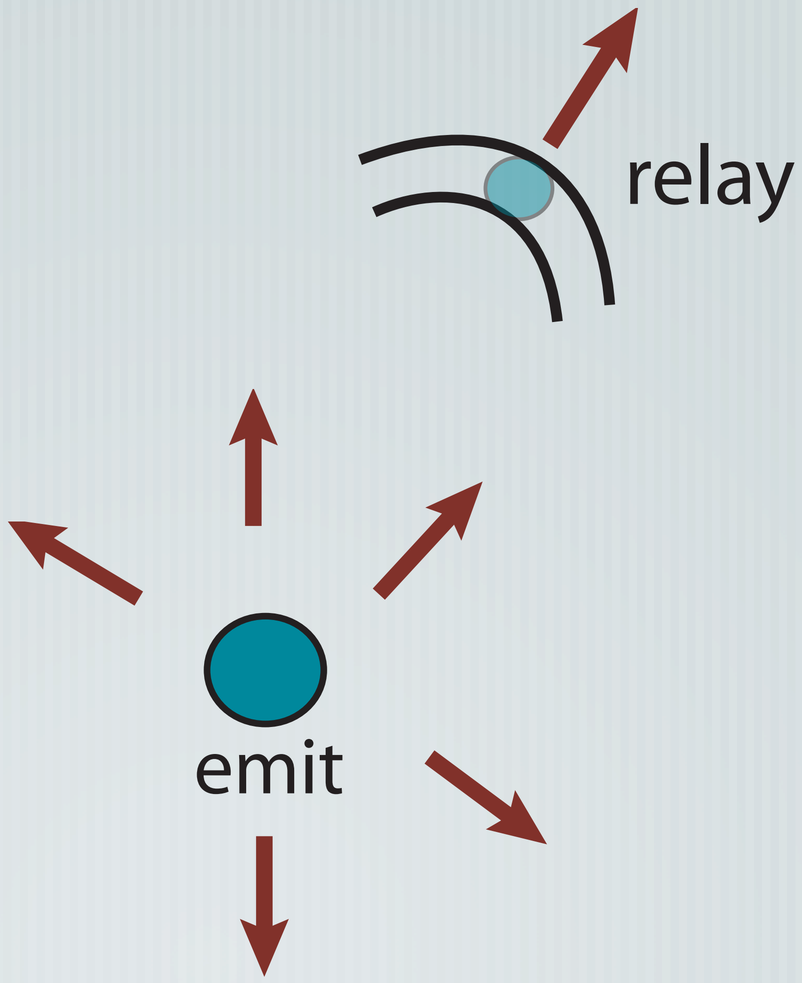
gemit(T,v)



Gradients

gemit(T,v)

grelay(T,v)

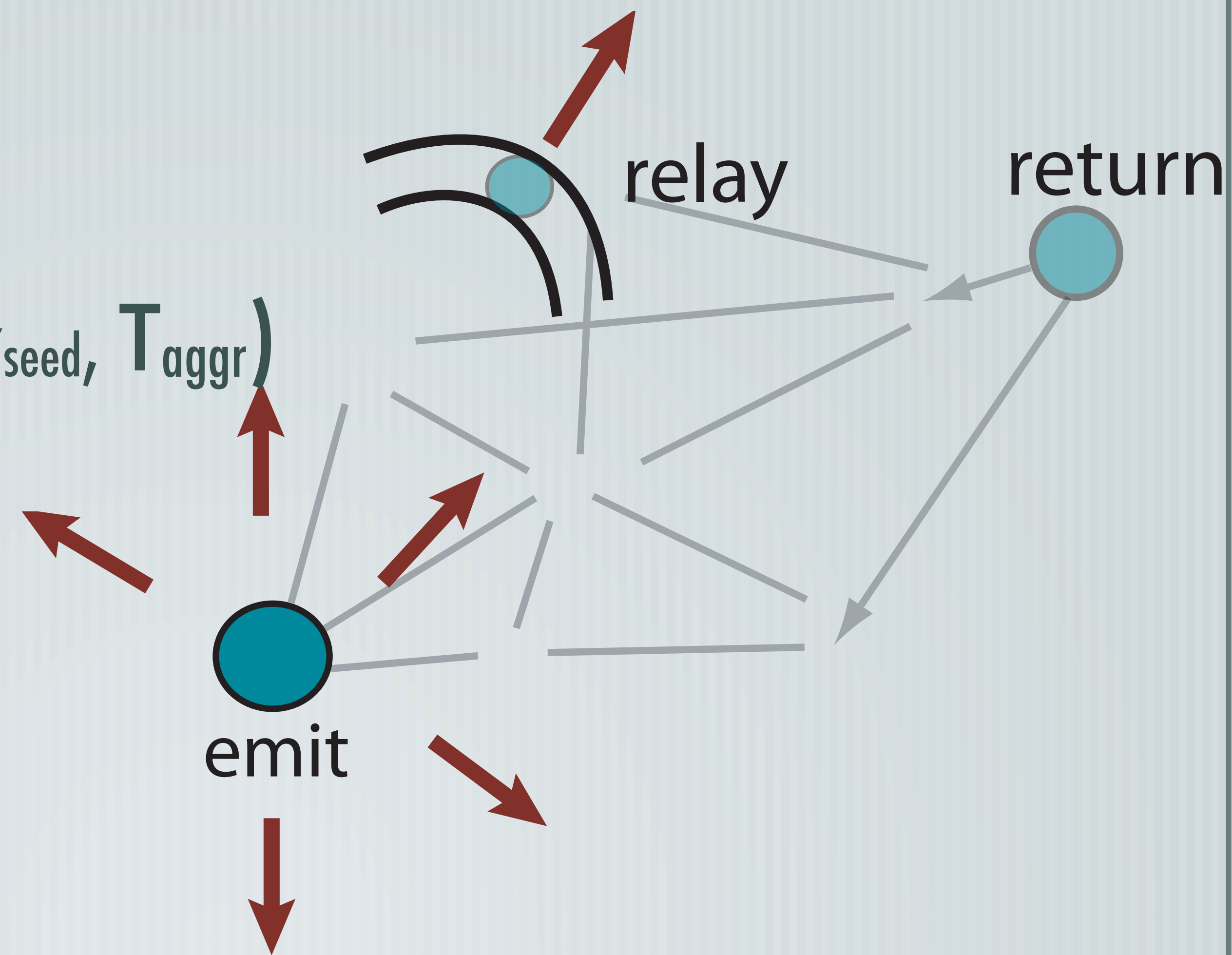


Gradients

gemit(T,v)

grelay(T,v)

greturn(v, T_{to}, T_{via}, v_{seed}, T_{aggr})



Gradients

gemit(T,v)

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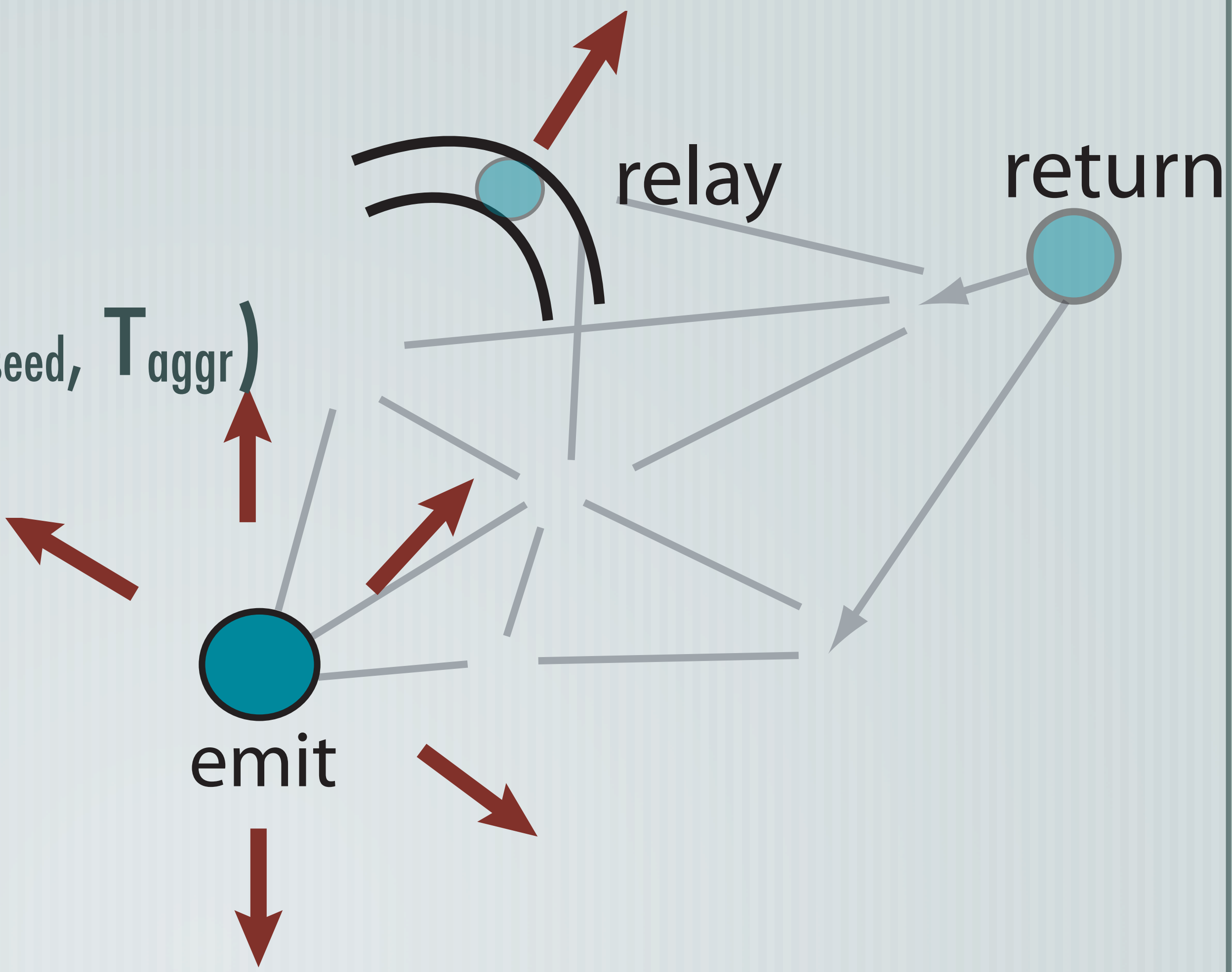
greturn(v, T_{to}, T_{via}, v_{seed}, T_{aggr})

Agnostic to routing and aggregation method



A data gathering program

```
startup Gather;
base_startup SparkGlobal;

token SparkGlobal() {
  gemit GlobalTree();
  timed_schedule SparkGlobal(10000);
}

token GlobalTree() {
  grelay GlobalTree();
}

token Gather() {
  greturn(subcall sense_light(),
          BaseReceive,
          GlobalTree,
          NULL, NULL);
  timed_schedule Gather(1000);
}
```

Protocol Stacks and Language Towers

Protocol Stacks and Language Towers

Bare Token Machines

Protocol Stacks and Language Towers

Returning Subcalls

Bare Token Machines

Protocol Stacks and Language Towers

subcall T(x) + 3

Returning Subcalls

Bare Token Machines

Protocol Stacks and Language Towers

Gradients

Returning Subcalls

Bare Token Machines

Protocol Stacks and Language Towers

Gradients

gemit(T,x...),
grelay(...), greturn(...

Returning Subcalls

Bare Token Machines

Protocol Stacks and Language Towers

Gradients

Returning Subcalls

Bare Token Machines

Protocol Stacks and Language Towers

Macros

Gradients

Returning Subcalls

Bare Token Machines

Protocol Stacks and Language Towers

flood(T)

Macros

Gradients

Returning Subcalls

Bare Token Machines

Protocol Stacks and Language Towers

elect-leader(...)

flood(T) Macros

Gradients

Returning Subcalls

Bare Token Machines

Protocol Stacks and Language Towers

Macros

Gradients

Returning Subcalls

Bare Token Machines

Protocol Stacks and Language Towers

?

Macros

Gradients

Returning Subcalls

Bare Token Machines

Compiling to TML

High level language: Regiment example

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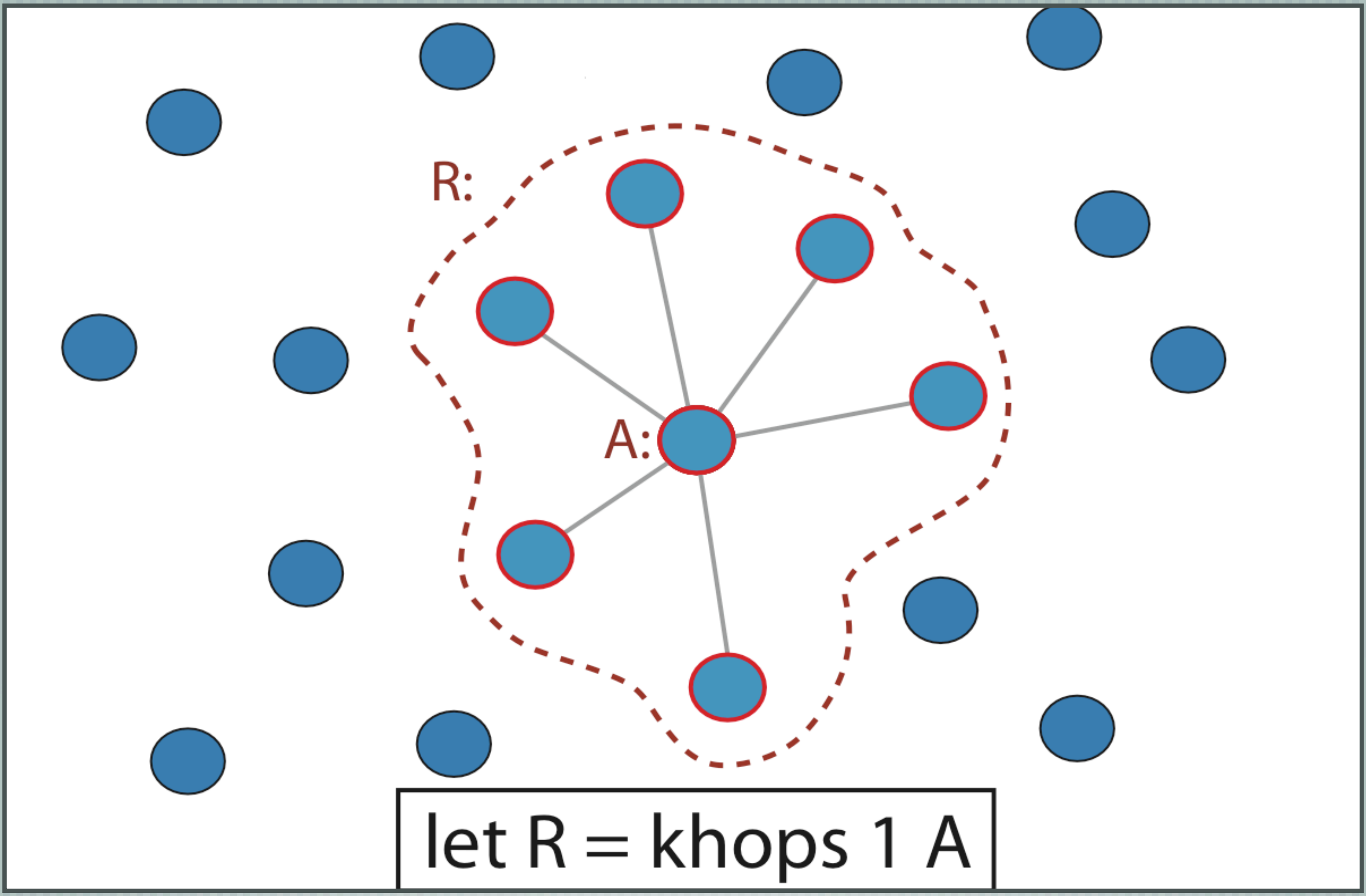

Wins for Regiment + TML

- Token namespace serves for region coordination:
  - Region membership = holding a token
  - Gradients used for constructing and aggregating all continuous regions

Future Work and Open Questions

- Dynamic loading
- Optimization: size
  - eliminating generated extra args
- Some dirty work.
- Implementation in real time OS?

The End.

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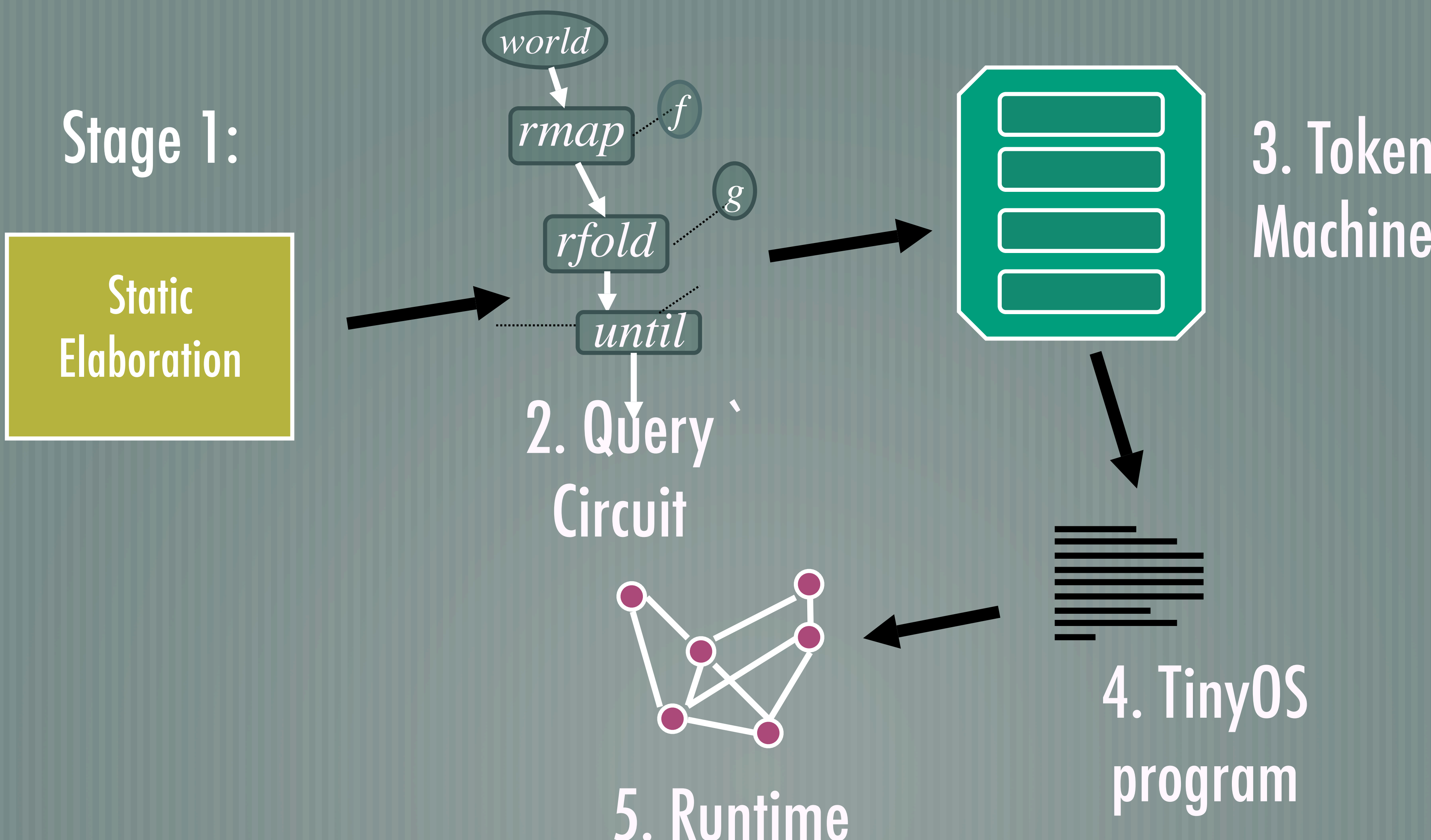
TML Advantages

- Atomicity is a simple semantic model for code generators and transformers to target
- Lightweight - no GC, no threads, no blocking
- Action abortion => real-time potential

Implementing Regiment



Motivation: macroprogramming

s1	349	23	2934	1
s2	302	10	29	3
s3	299	0	0	8
s4	105	0	1099	0
...	...	...	...	...

t

t+1

...

Sensor Data

Motivation: macroprogramming

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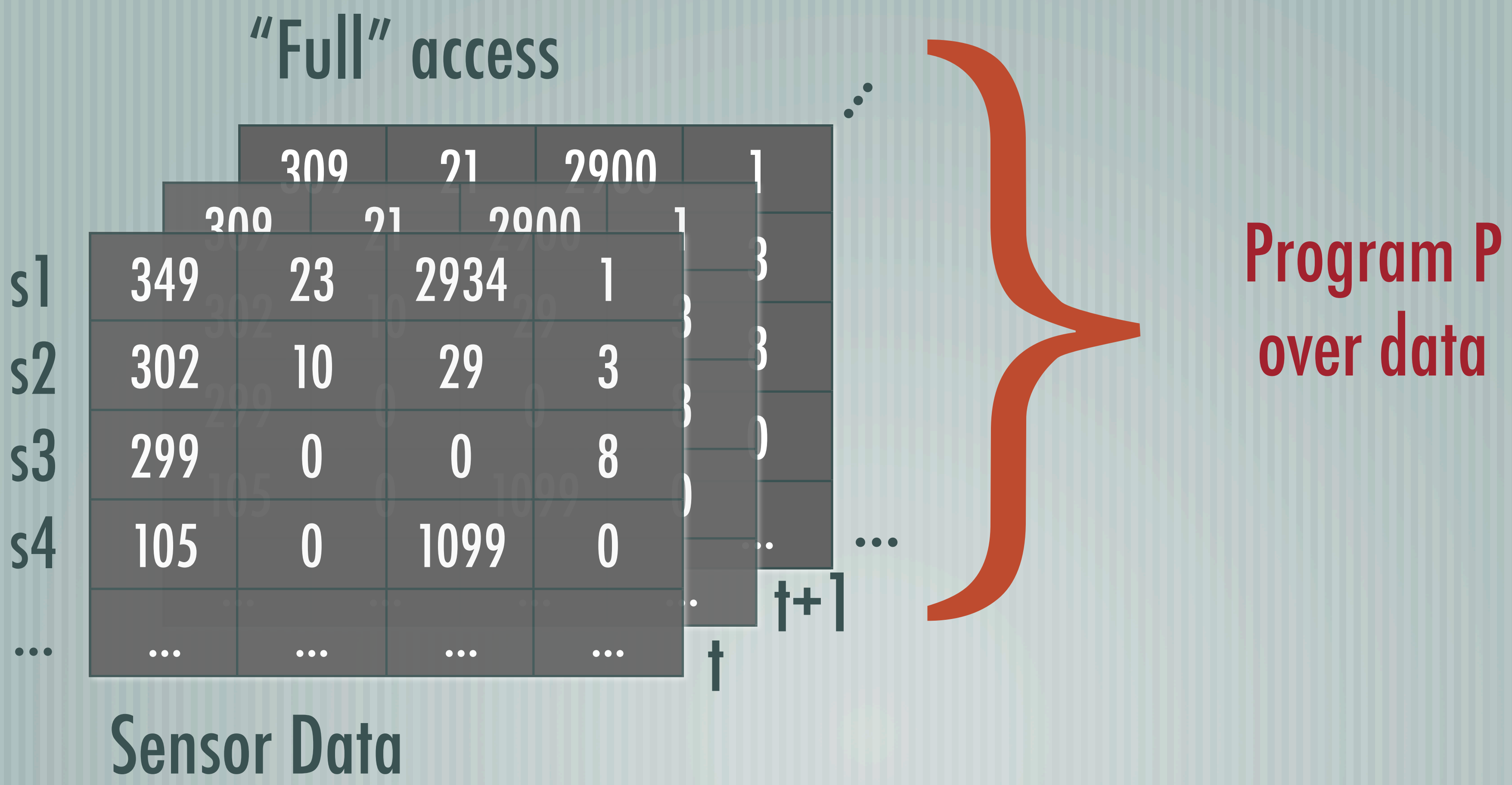
Sensor Data

Program P over data

Motivation: macroprogramming



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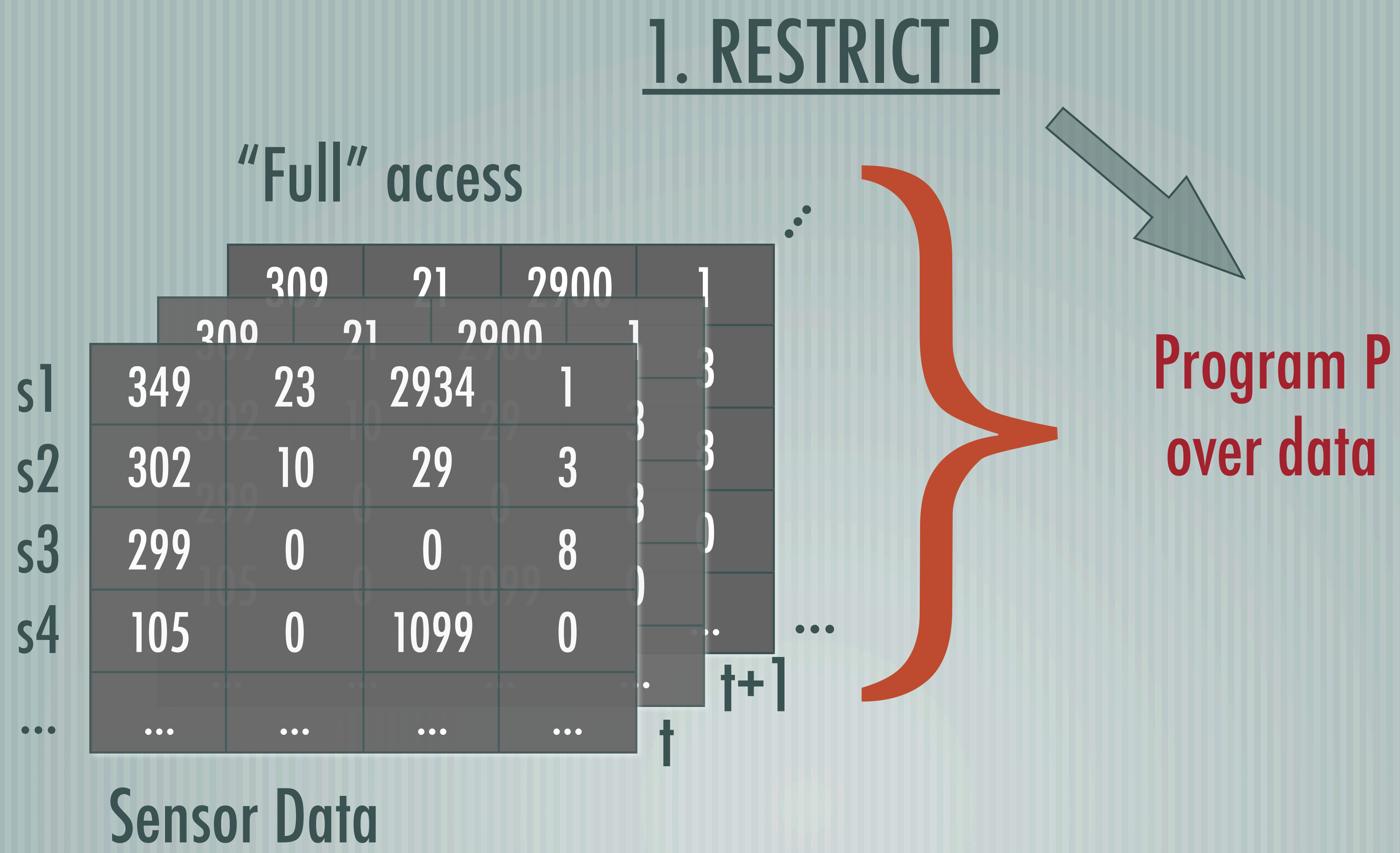

Motivation: macroprogramming

1. RESTRICT P

"Full" access

s1	349	23	2934	1
s2	302	10	29	3
s3	299	0	0	8
s4	105	0	1099	0
...	...	...	...	...

t

t+1

...

Sensor Data

Program P over data

2. PUSH P IN-NETWORK