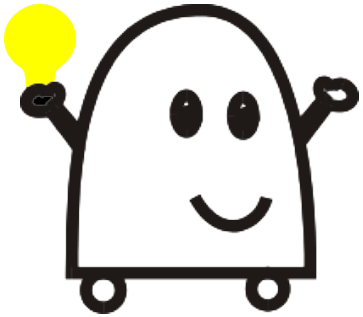
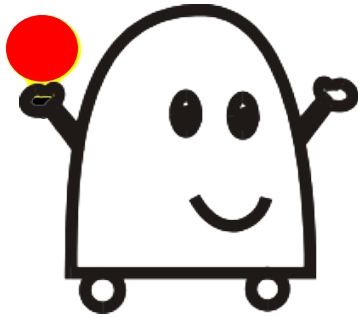
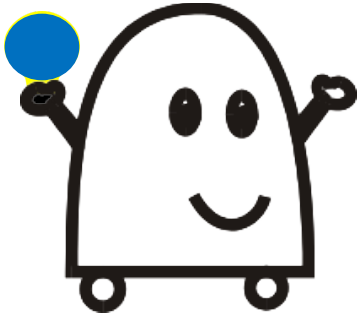


Computations by Luminous Robots



Giuseppe Prencipe

Università di Pisa



Swarms of robots

Many

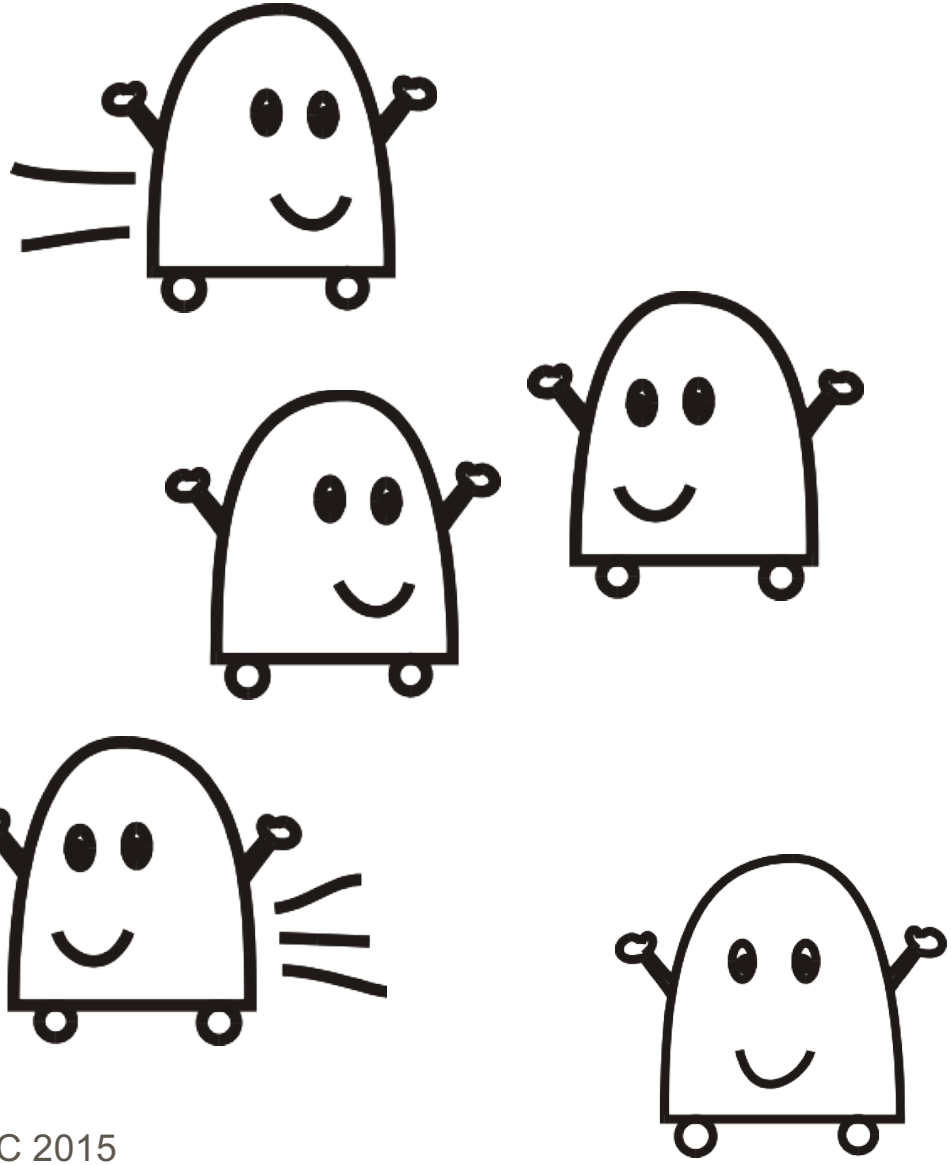
Very Simple

Generic

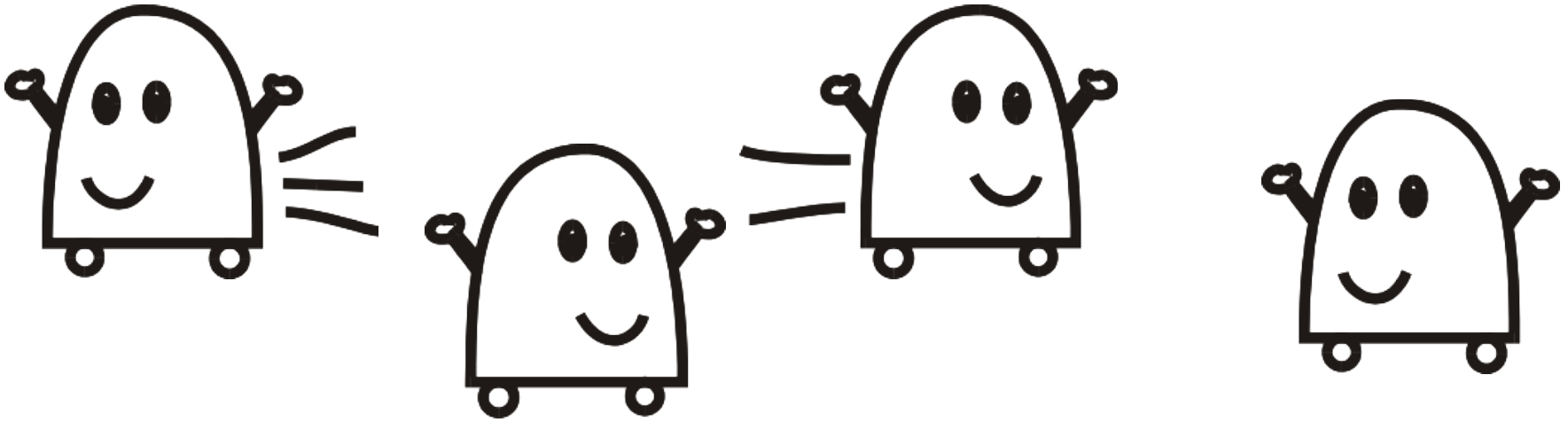
Identical

Autonomous

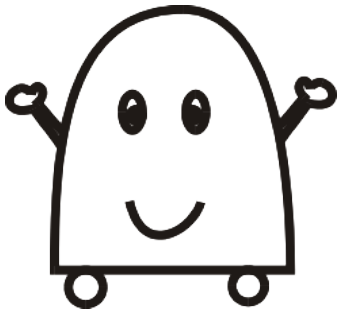
Silent



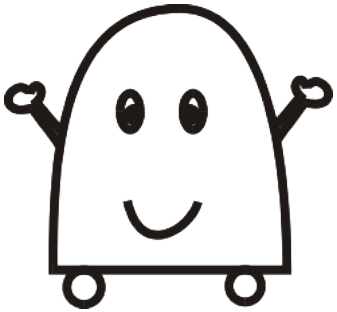
Swarms of robots



- A robot - **alone** - is computationally **weak**
- **Cooperation** of robots is essential
  to perform complex tasks



Mobile Robots

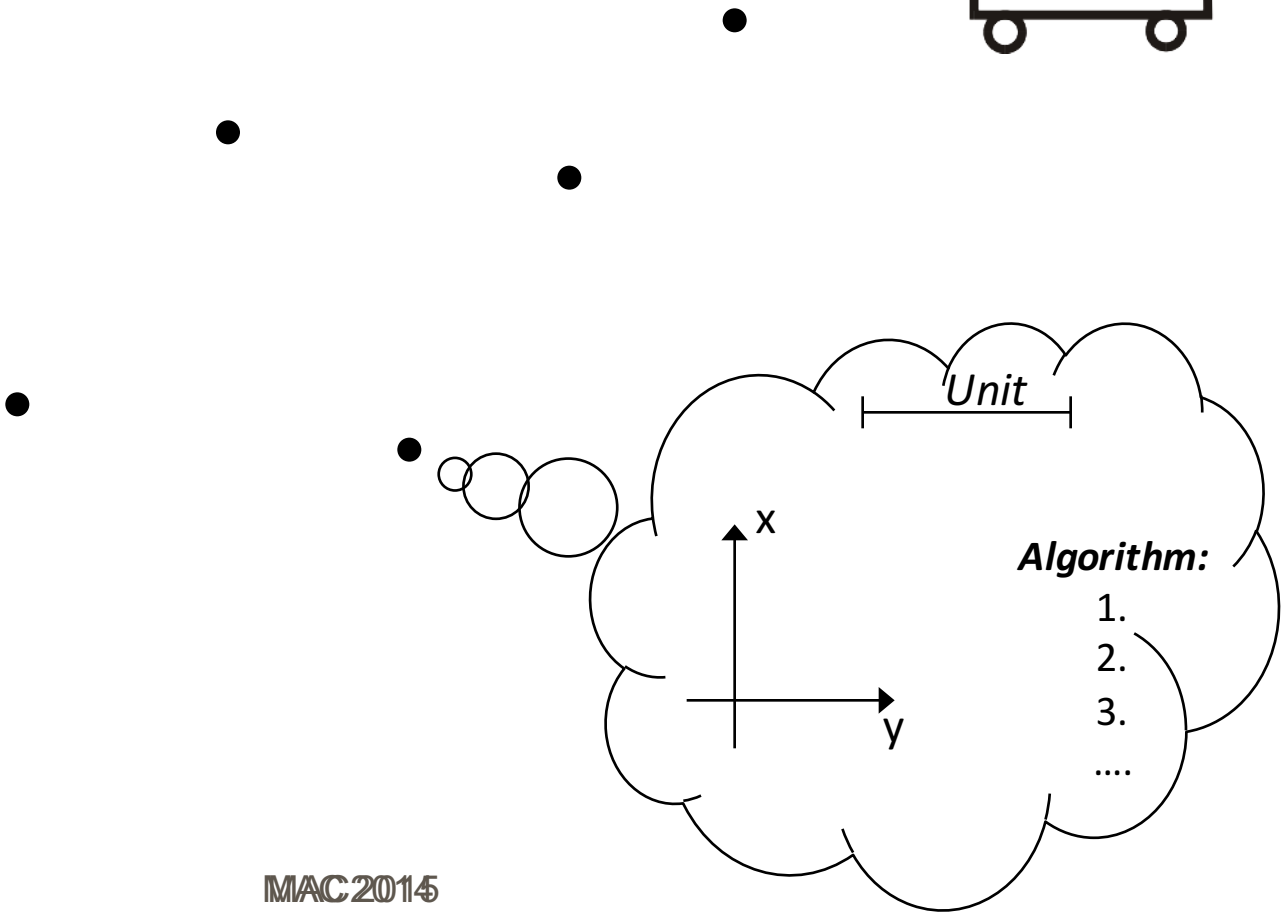


Autonomous

Homogeneous

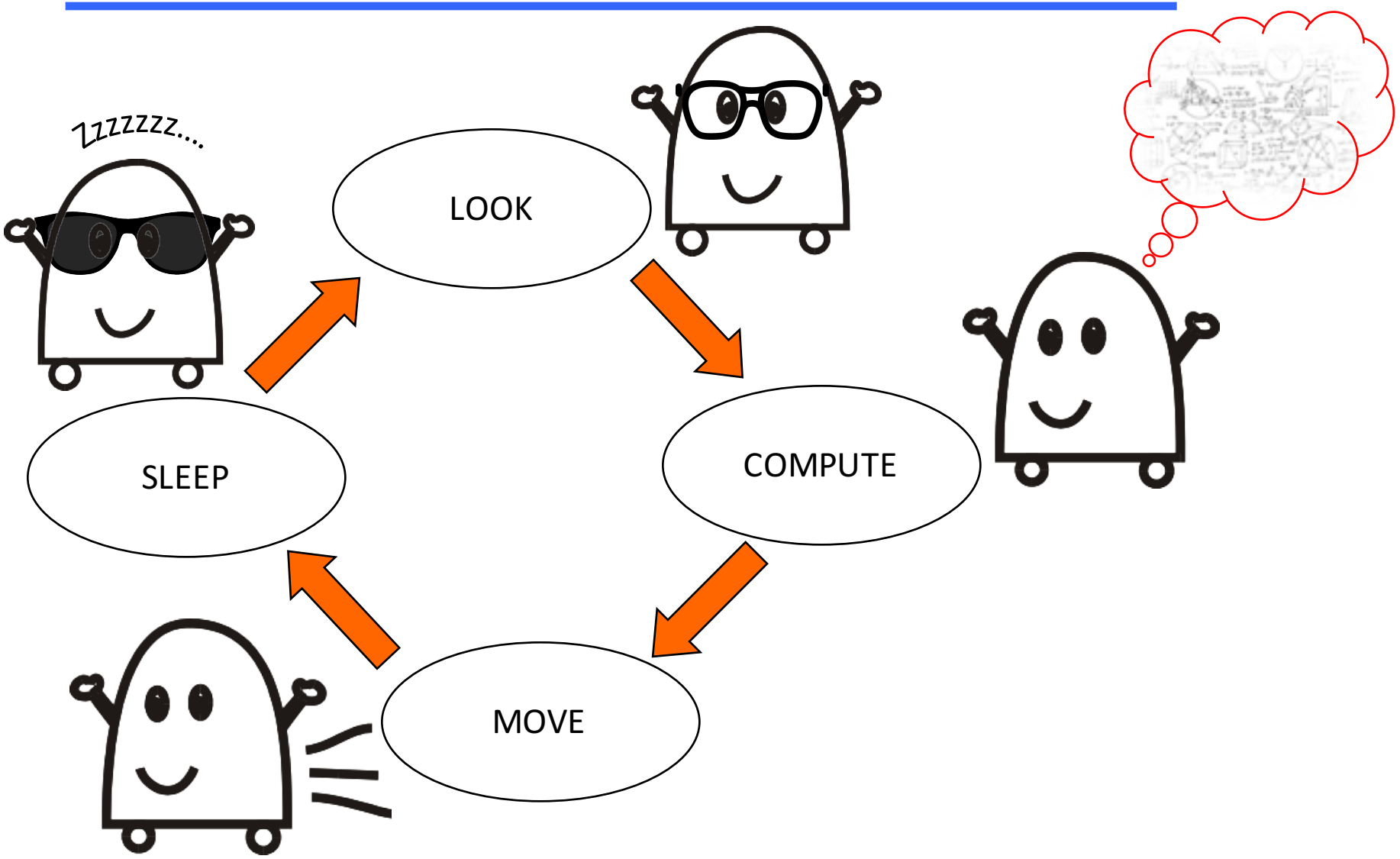
Identical

Silent



viewed as points

Robot's behaviour : Life Cycle

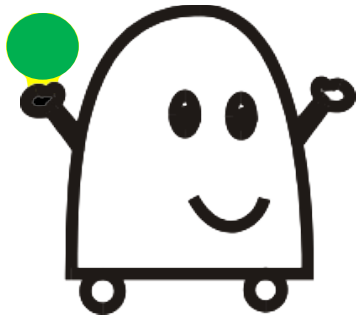


Powerful? Restricted?

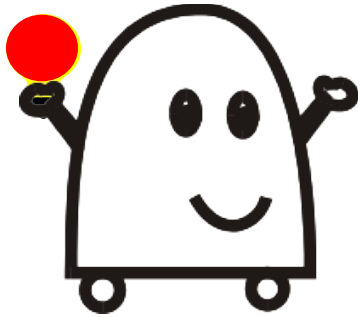
- Precision
- Dimensionless

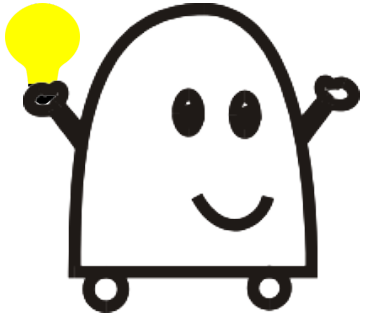
- Communication

Luminous Robots

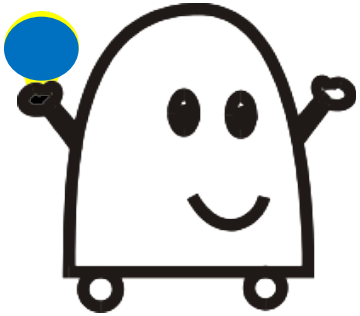


The robots are still oblivious

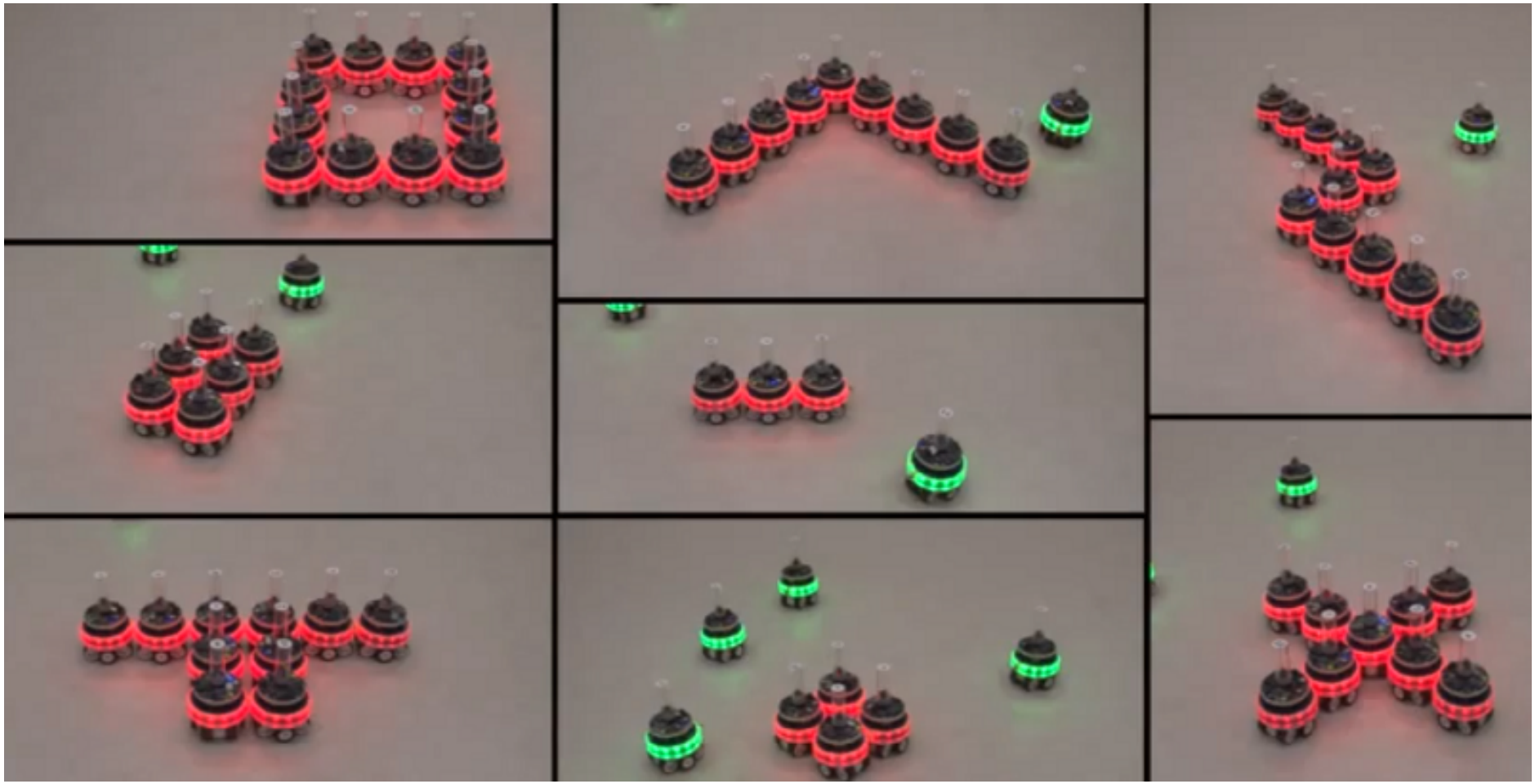




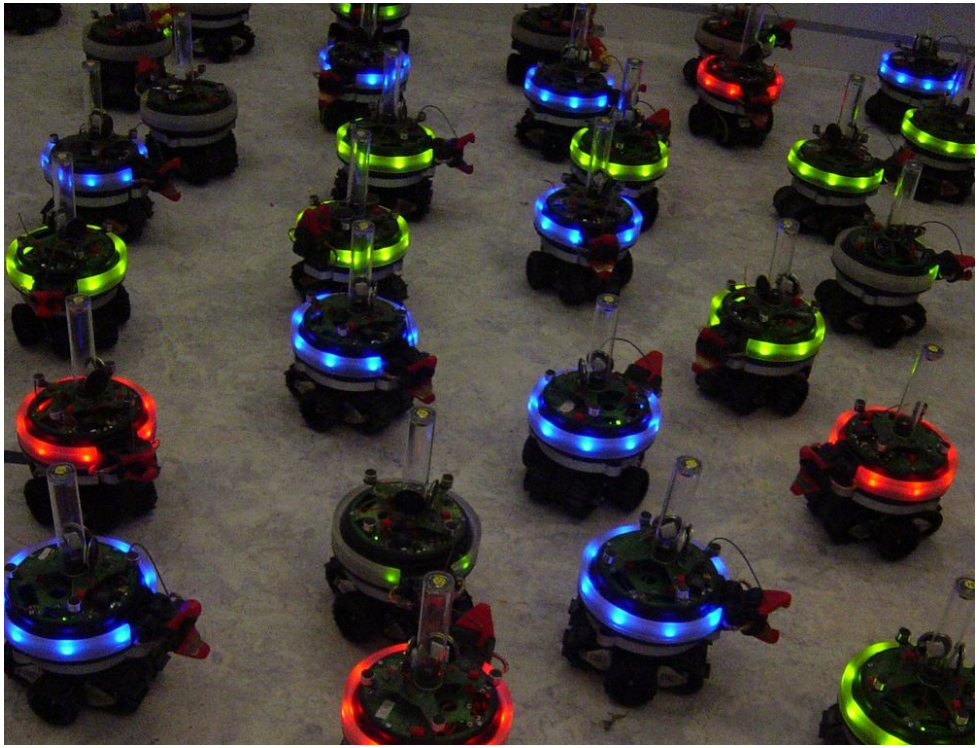
But they are enhanced
with **VISIBLE LIGHTS**
that can change **color**



Robots' swarm with Lights



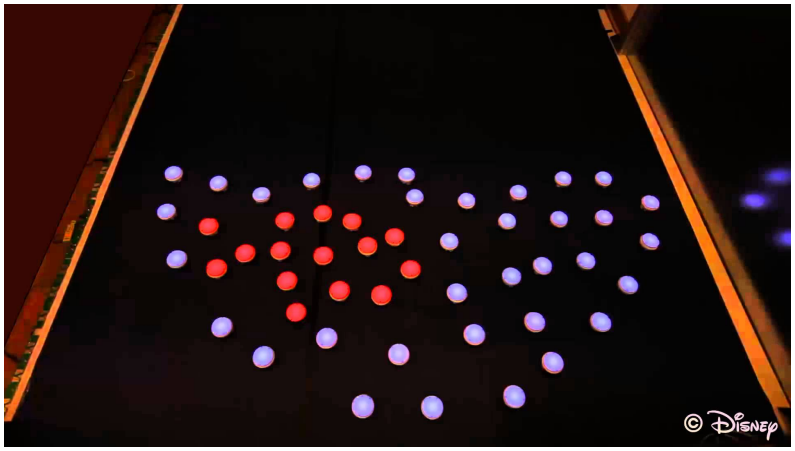
S-bots: Light ring for communication. Each of the 8 sectors of the light ring can take RGB colours and can blink at different frequencies (the ring is observed with the omnidirectional camera)



S-bots: Light ring for communication. Each of the 8 sectors of the light ring can take RGB colours and can blink at different frequencies (the ring is observed with the omnidirectional camera).

Robots' swarm with Lights

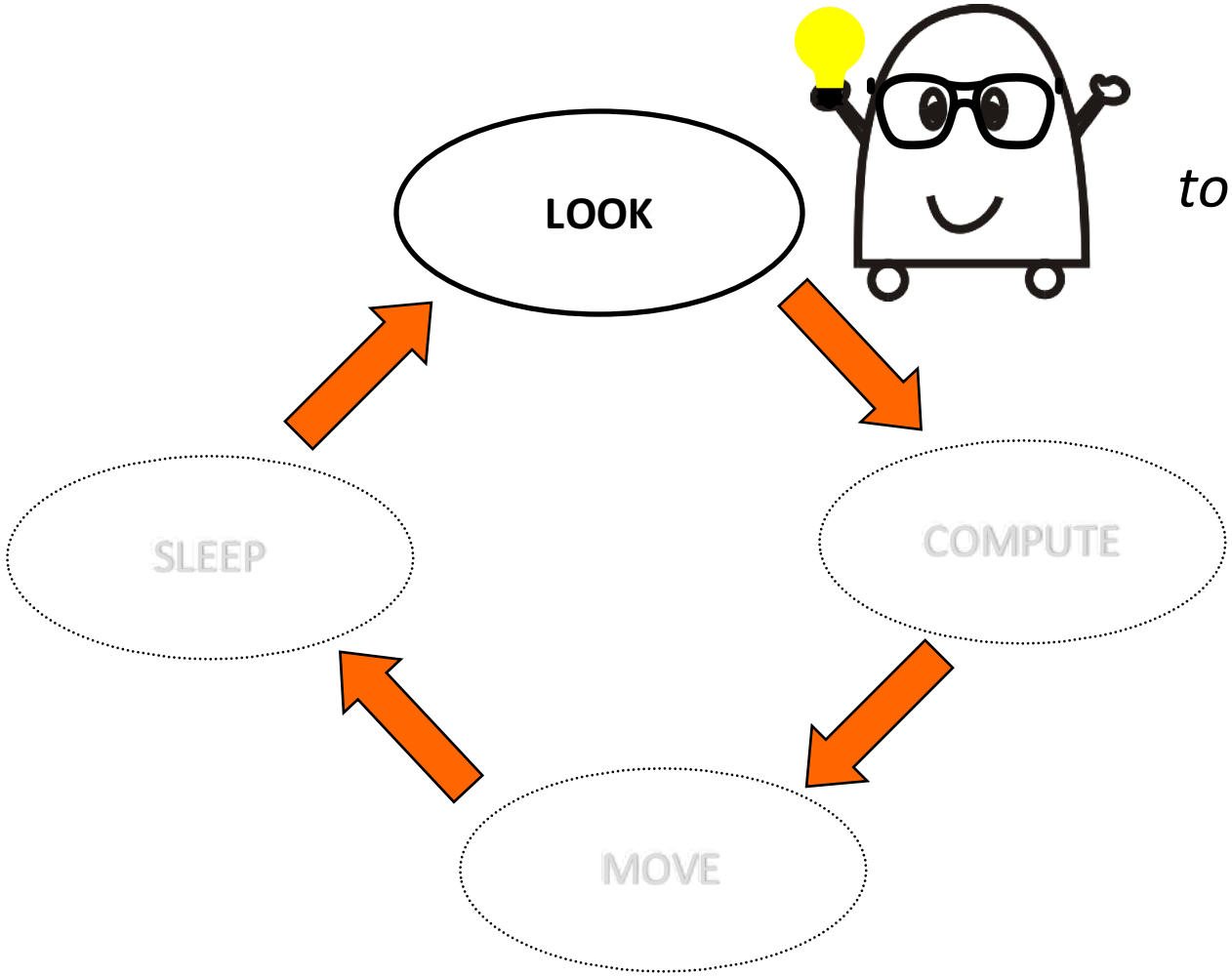
Robot Swarm, currently at the MoMath's exhibit in NY: Robots who react to your presence and communicate with each other, chasing after you or zooming away as you move across the floor.



Display Swarm (Disney research): new kind of display composed of a mobile robot swarm (**Pixelbots**). Each robot acts as an individual pixel and has controllable color. The swarm is used to make representational images and animated movies.

Computational model

Robot's behaviour : Life Cycle



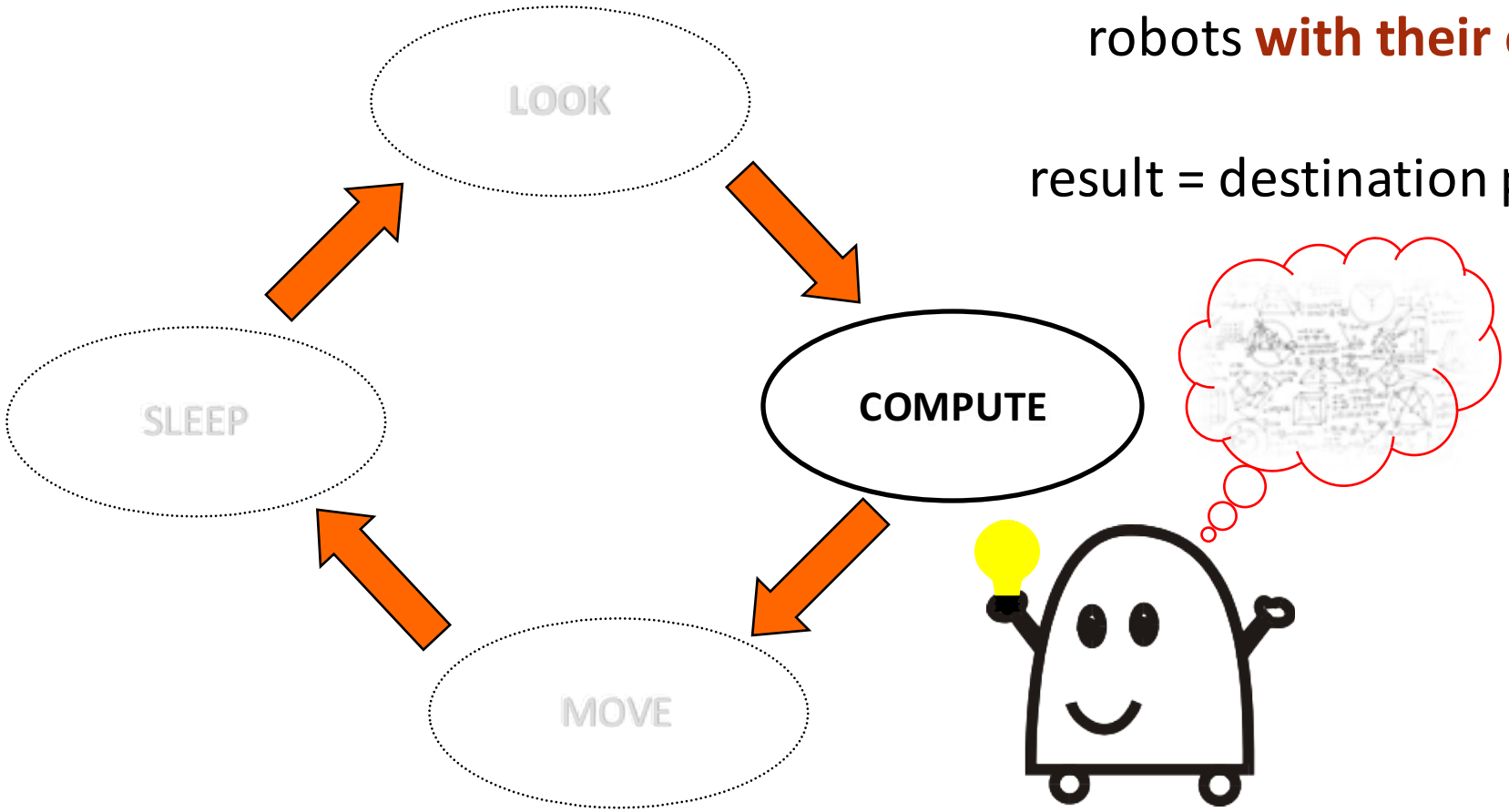
Uses its sensors to observe the world.

result = **colored SNAPSHOT** of the world

Robot's behaviour : Life Cycle

input = position of the other robots **with their color**

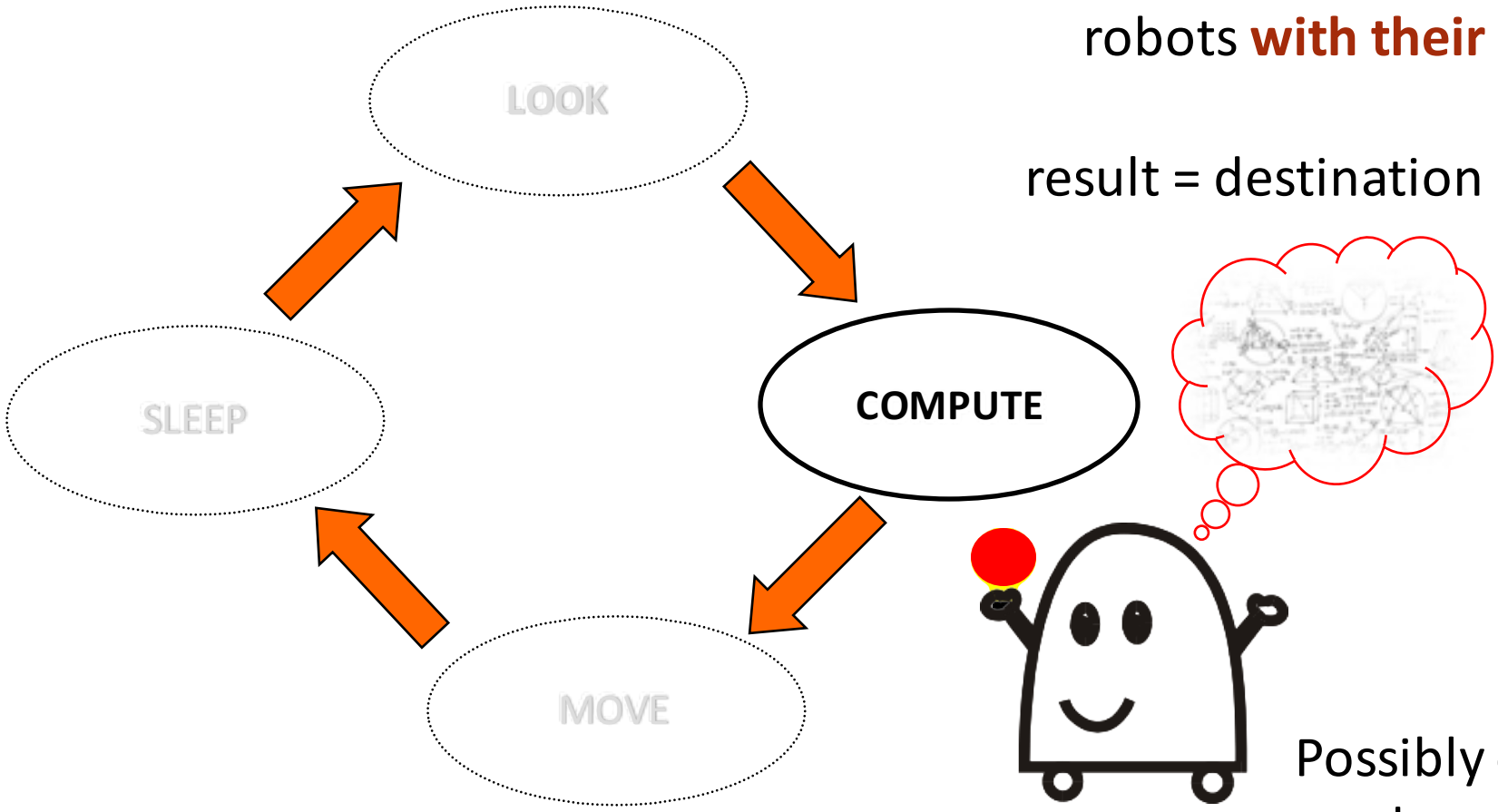
result = destination point



Robot's behaviour : Life Cycle

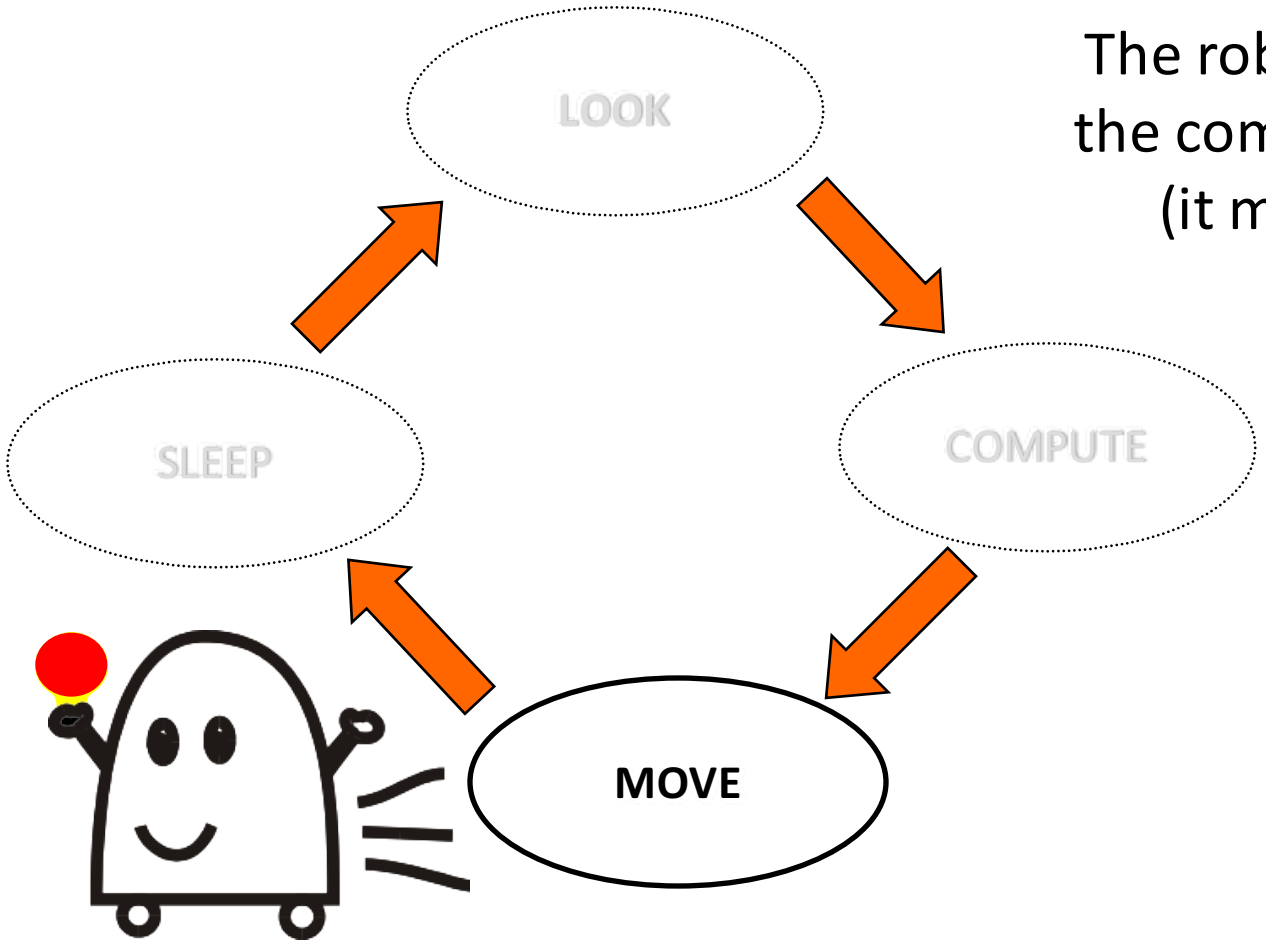
input = position of the other robots **with their color**

result = destination point



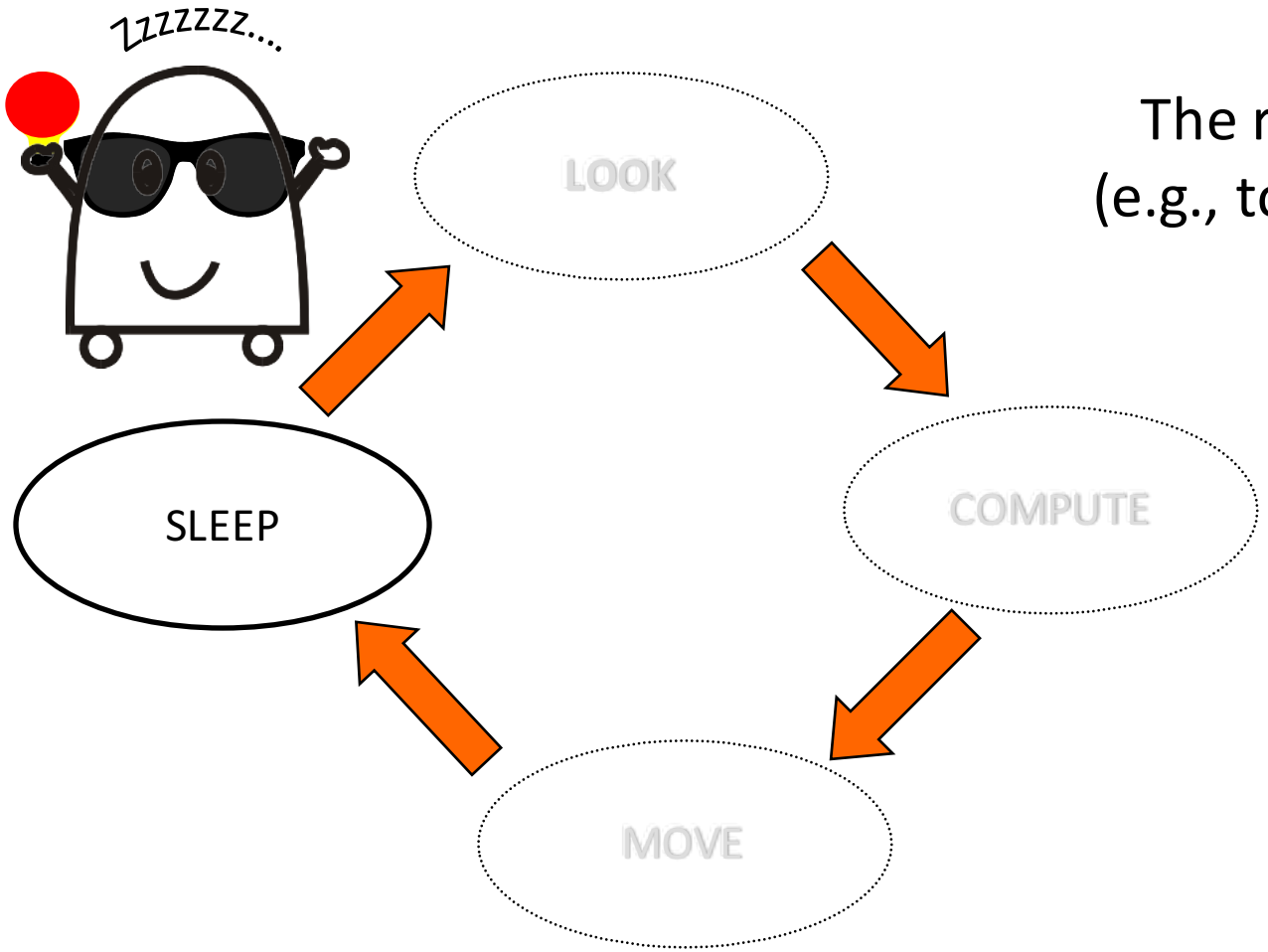
Possibly change color of light

Robot's behaviour : Life Cycle



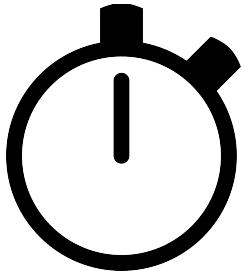
The robot moves *towards* the computed destination (it might not reach it)

Robot's behaviour : Life Cycle



The robot may be idle
(e.g., to recharge battery)

Time – Synchronous/Semi-Synchronous

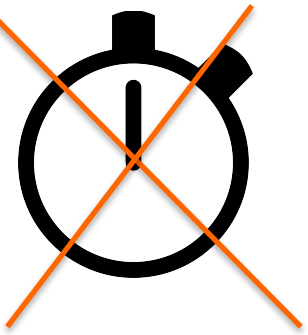


There is a **global clock tick** reaching all robots simultaneously

At each clock tick **every robot is either active or inactive**, and only active robots perform their cycle **atomically**

In **Fully Synchronous**: all robots are active at each step
In **Semi-Syncrhonous**: a subset of robots is active in each step

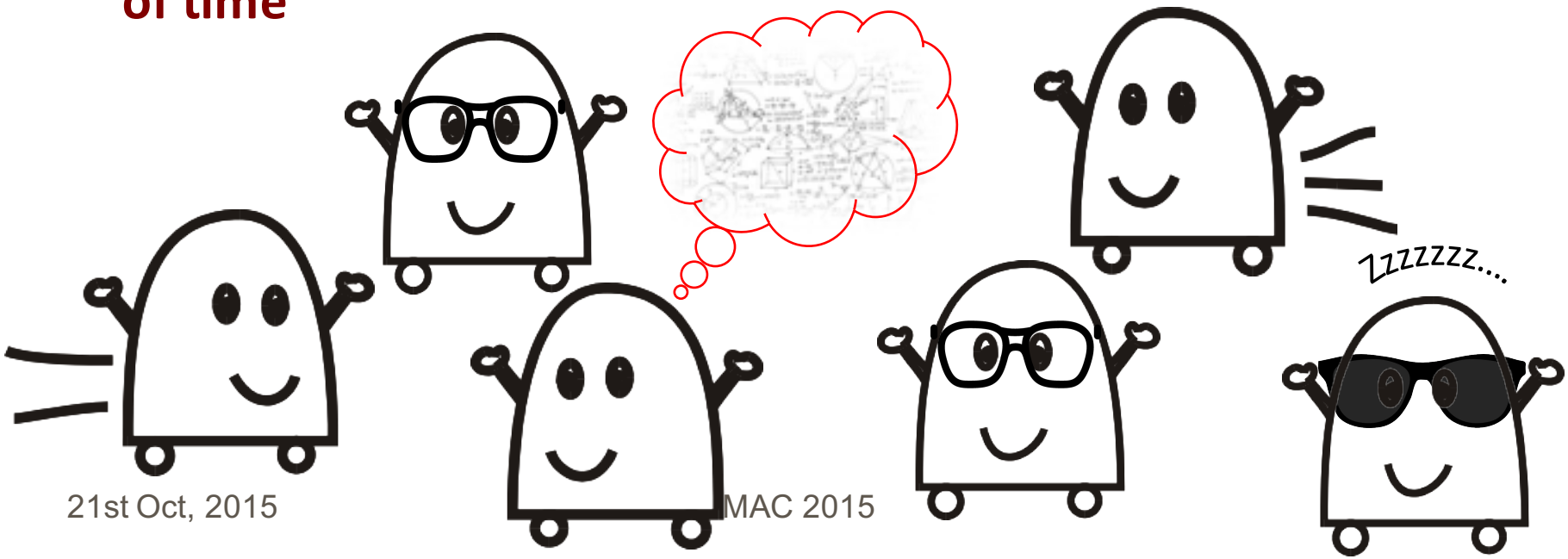
Time – Asynchronous (ASYNC)

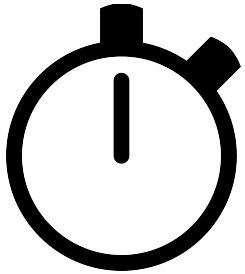


There is **no global clock**

Robots are active and perform their operations **independently** and **asynchronously**

Compute and **Move** take a bounded but **unpredictable amount of time**





Luminosity and Synchrony

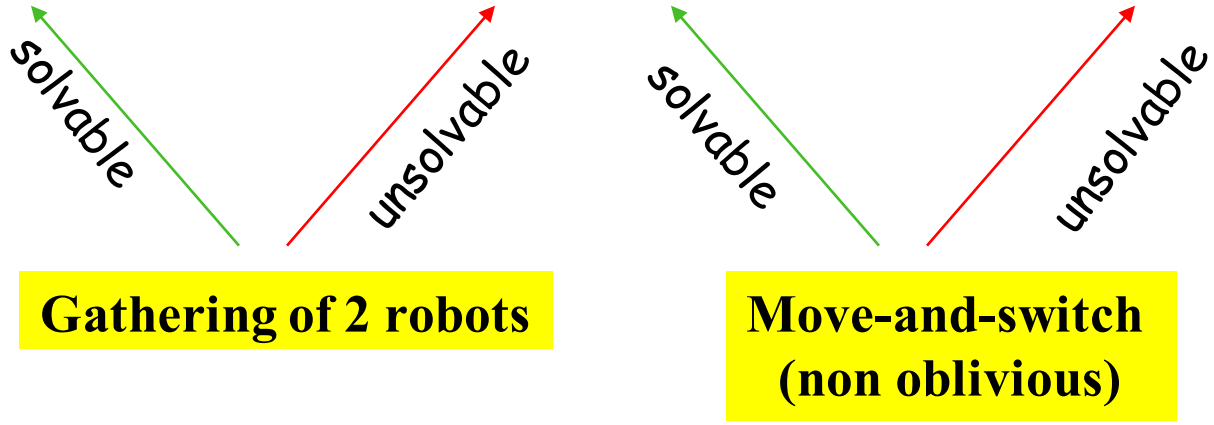
[Das, Flocchini, Prencipe, Santoro, Yamashita, TCS 2015]

For non-luminous robots

FSYNCH > SSYNCH > ASYNCH

For non-luminous robots

FSYNCH > SSYNCH > ASYNCH



- **Move** along x axis
- **Switch** to moving along y only after
  1. I observed all others in at least 3 different positions, **and**
  2. I have been observed in at least 3 different positions

Impact of Lights

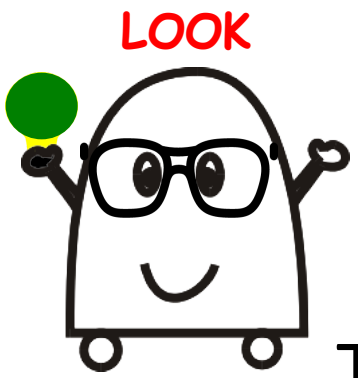
1. Any problem solvable in SSYNC without lights is also solvable in ASYNC with lights

ASYNC + lights >= SSYNC

Let ***A*** be an algorithm that solves problem **P** in SSYNC

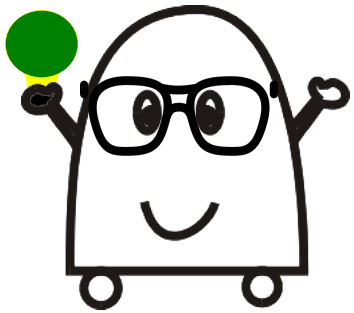
There exists an algorithm ***B*** in **ASYNC + lights** (5 colors) in which every execution is equivalent to a SSYNC execution of **A**

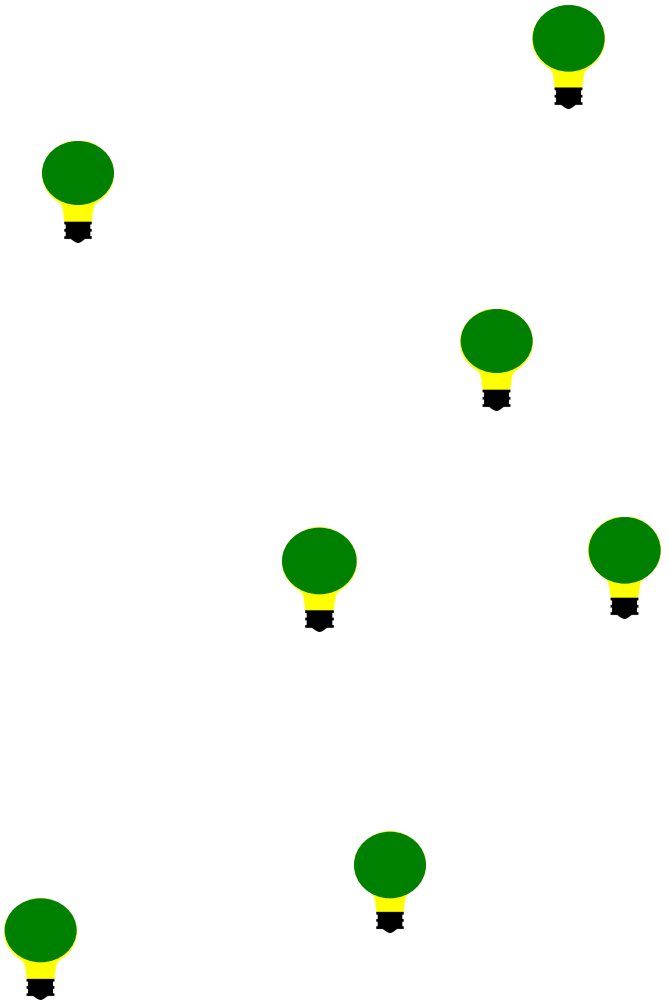
There exists an algorithm ***B*** in **ASYNC+lights** (5 colors) in which every execution is equivalent to a SSYNC execution of **A**

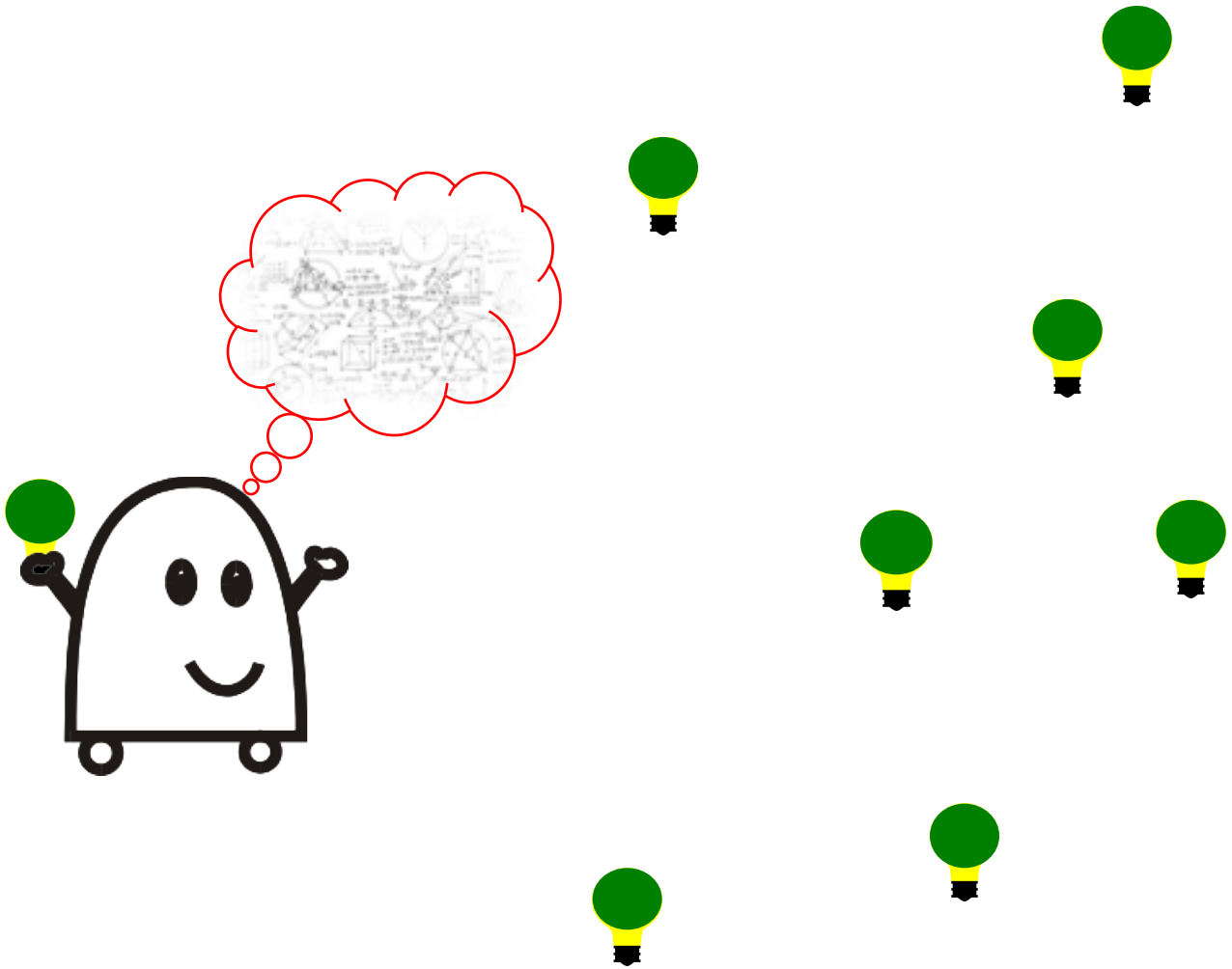


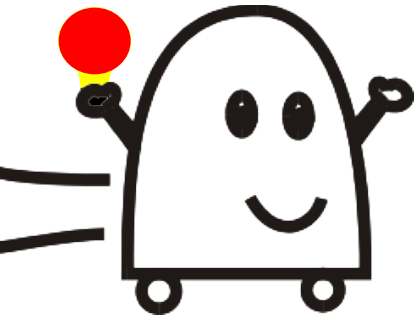
To simulate a SSYNC execution:
I **COMPUTE** and **MOVE** according to algorithm **A**
only if the colors I see indicate that
my movement is consistent with a SSYNC execution

If it is a ***safe-snapshot***

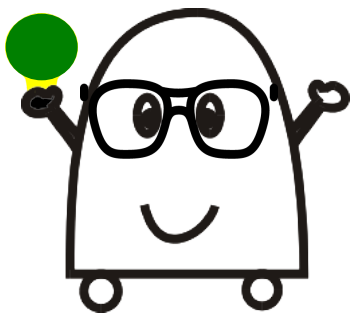


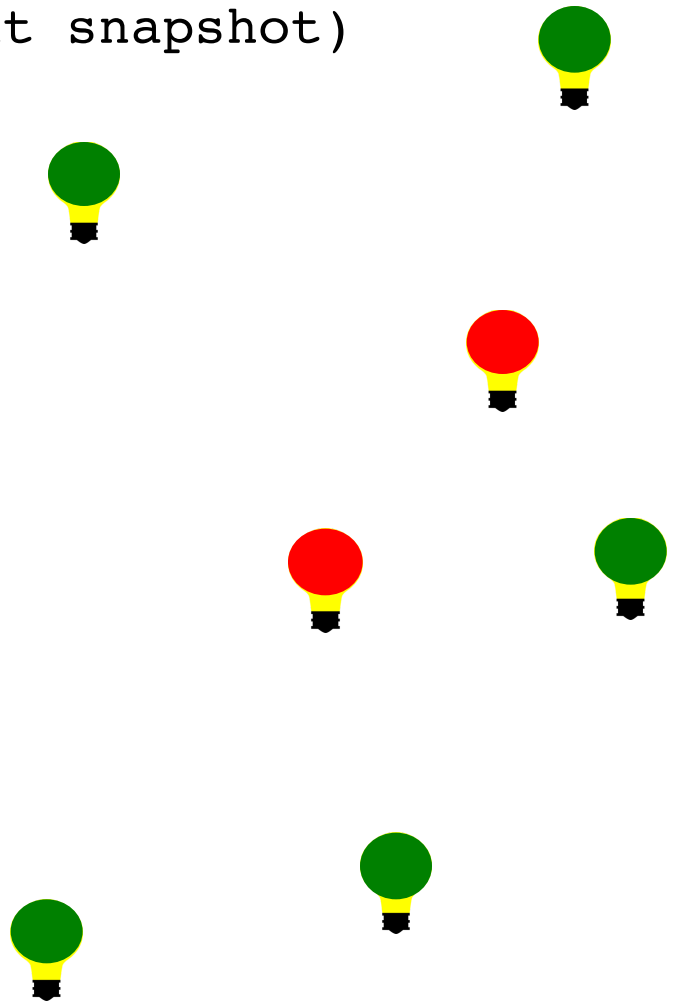


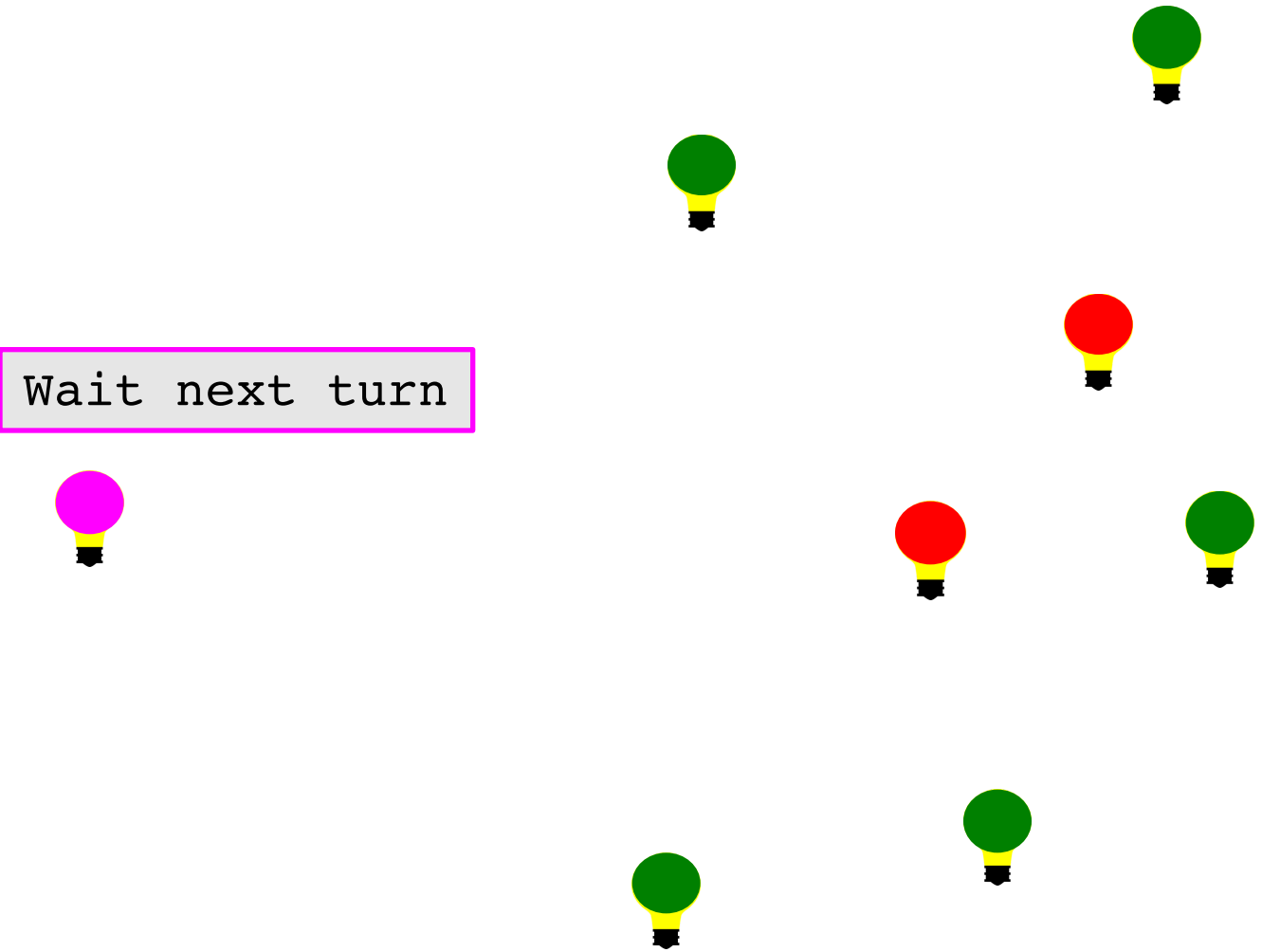


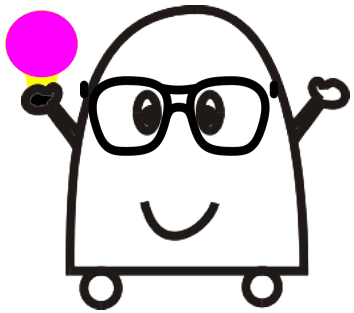


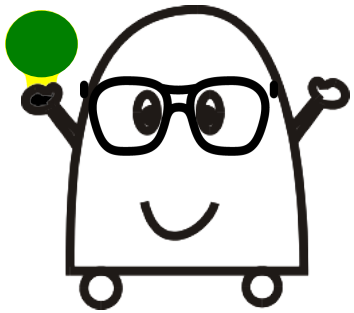
If it is **not a safe snapshot**
(i.e. someone is moving on the basis
of a different snapshot)

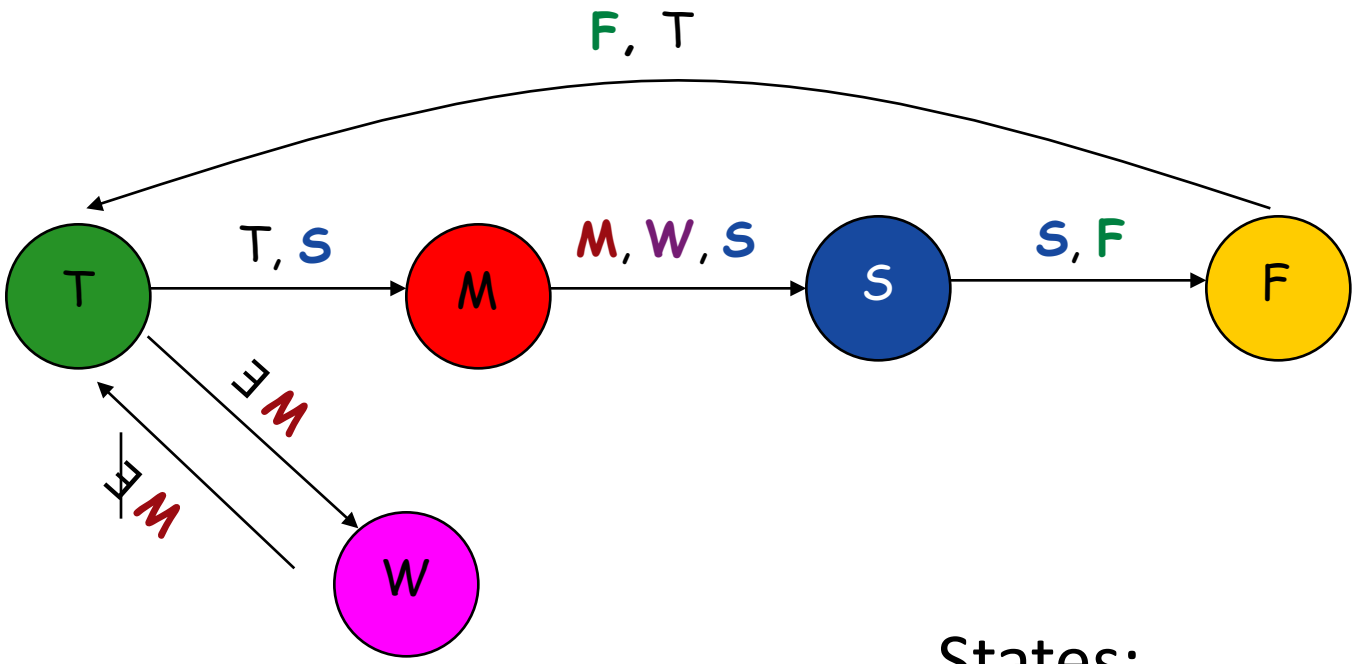





Wait next turn







States:

T(rying)
M(oving)
S(topped)
F(inished)
W(aiting)

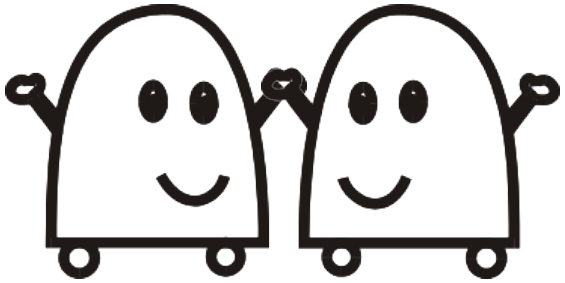
Impact of Lights

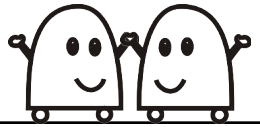
2. There are problems unsolvable in SSYNC without lights, but solvable in ASYNC with lights

Gathering of two robots

ASYNC + light > SSYNC

Gathering of 2 robots without lights

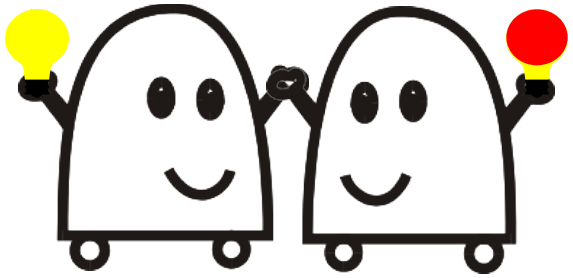


	
FSYNCH	yes
SSYNCH	impossible
ASYNCH	impossible

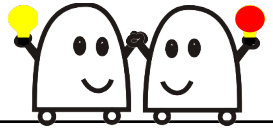
Exactly in the same point

Suzuki, Yamashita, SIAM J. Comp 1999

Gathering of 2 robots with lights



ASYNCH + lights > SSYNC

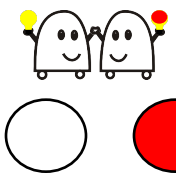
	
FSYNCH	yes
SSYNCH	yes
ASYNCH	yes

[Viglietta, ALGOSENSORS 2013]

(2 colors, optimal)

(4 colors)

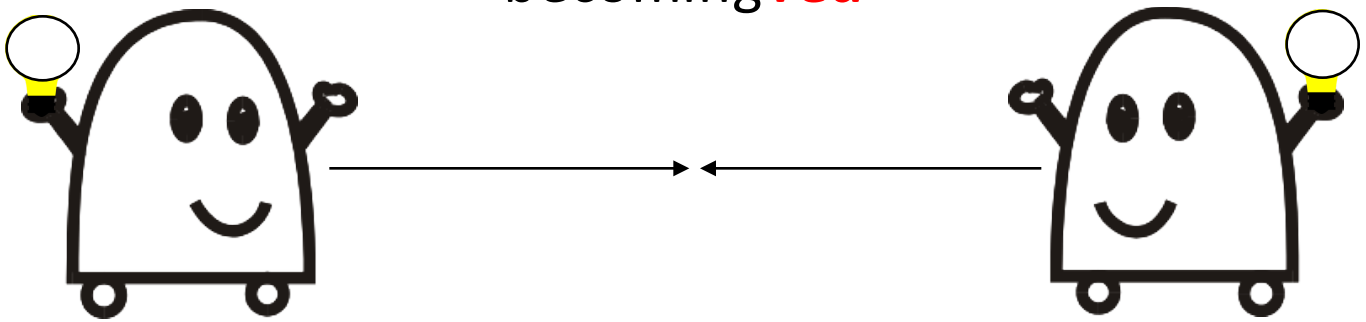
[Das, Flocchini, Prencipe, Santoro, Yamashita, TCS 2015]



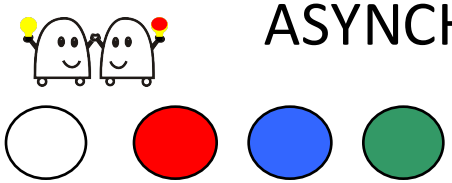
ASYNCH

Main Idea

If we are both white, I move towards you, becoming **red**



If this combination occurs, we get CLOSER to the solution



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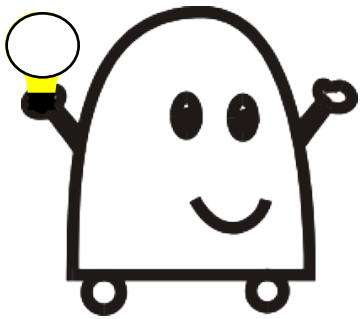

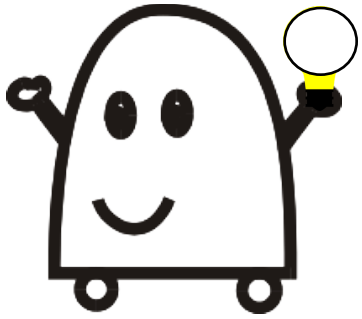

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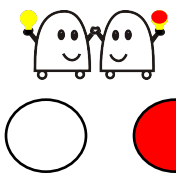
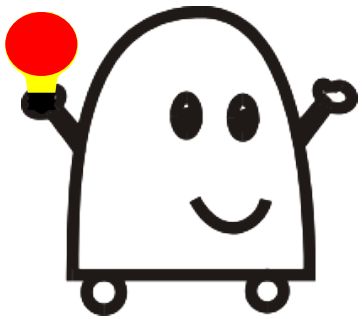
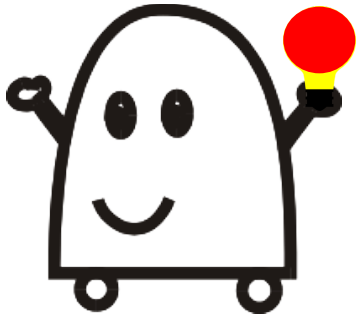


ASYNCH

Main Idea

If we are both white, I move towards you, becoming **red**

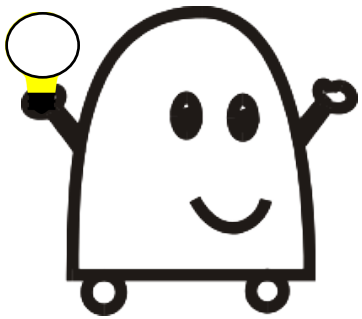




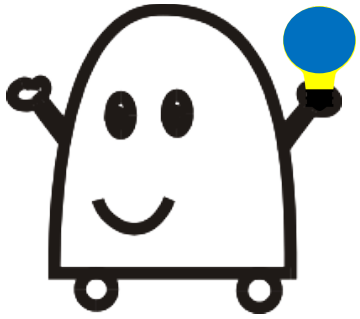
If this combination occurs, we get CLOSER to the solution

Main Idea

if I am white and I see you **blue** I move towards you



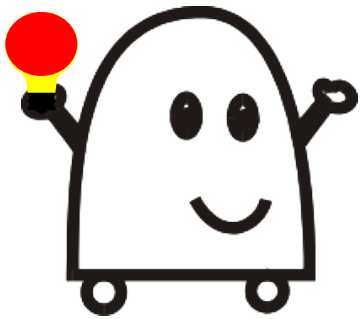
if I am **blue** and I see you white, I don't move.



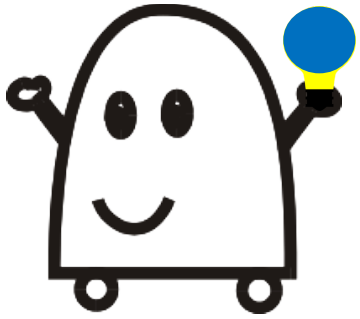
If this combination occurs, we get CLOSER to the solution

Main Idea

if I am white and I see you **blue** I move towards you



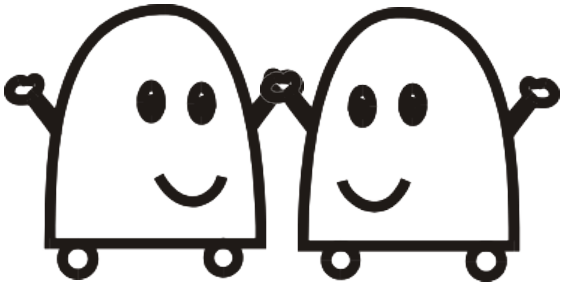
if I am **blue** and I see you white, I don't move.



If this combination occurs, we get CLOSER to the solution

Main Idea

The algorithm guarantees that those combinations occur periodically until the two robots eventually gather

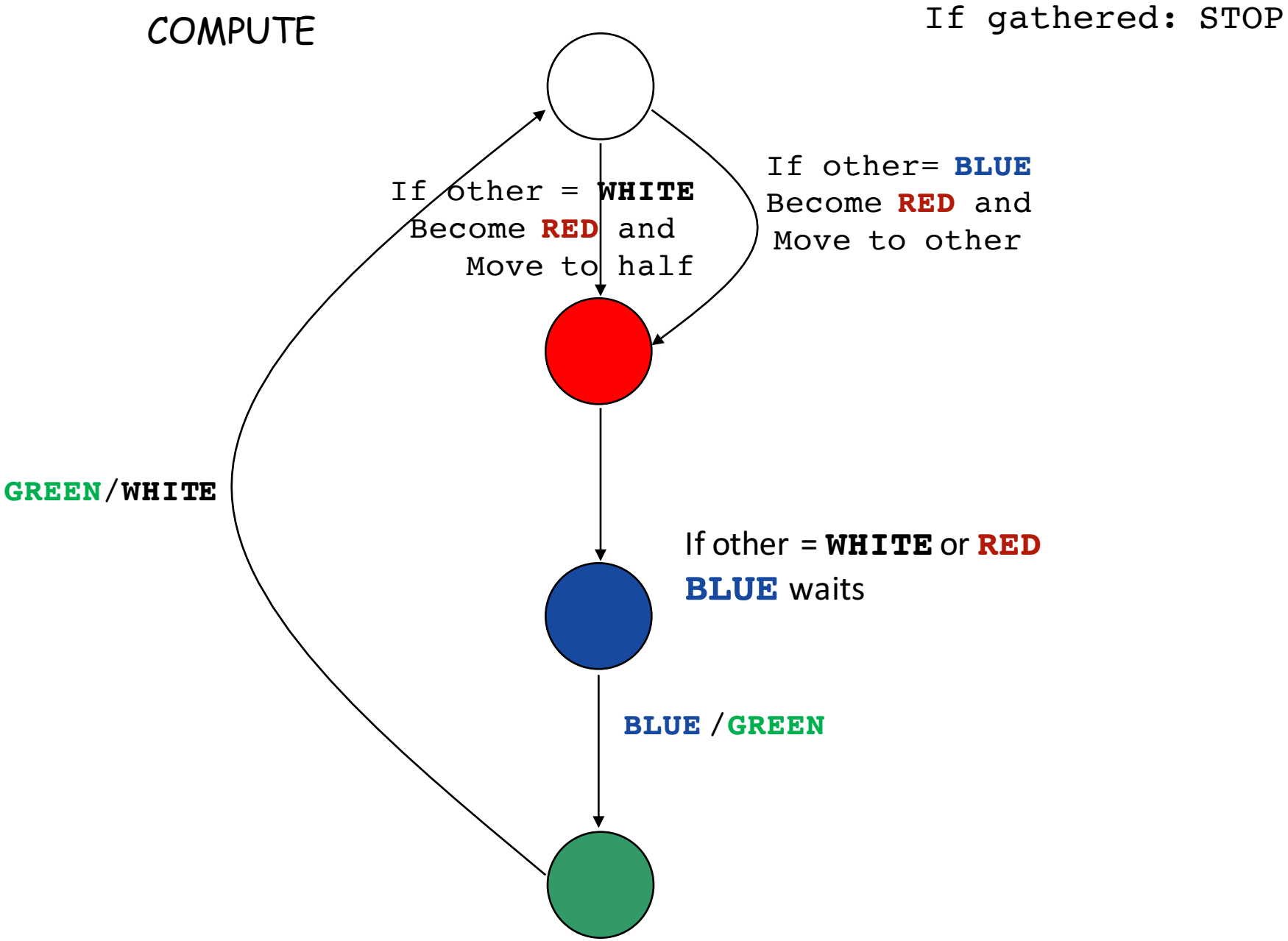


Starting

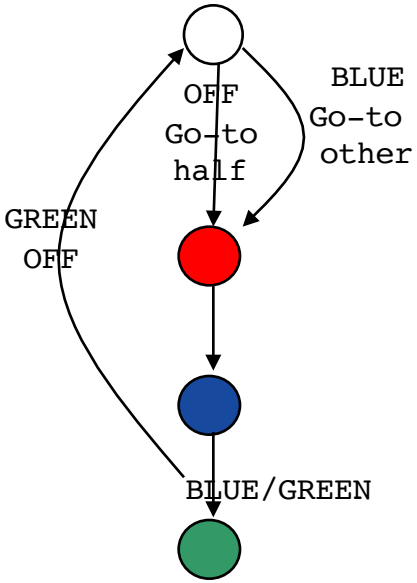
Moving

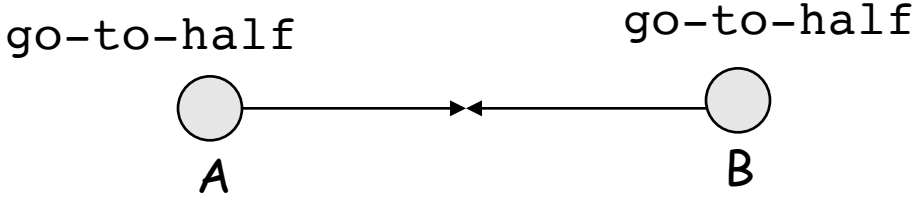
Waiting for you

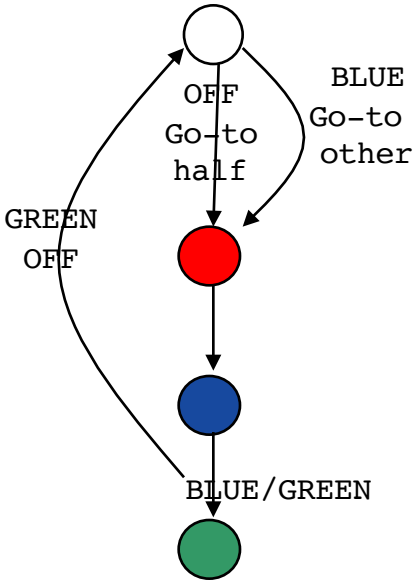
Not Waiting anymore,
will become White again

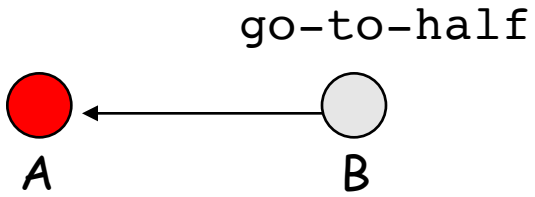

COMPUTE
If gathered: STOP
If other = WHITE
Become RED and
Move to half
If other= BLUE
Become RED and
Move to other
GREEN/WHITE
If other = WHITE or RED
BLUE waits
BLUE /GREEN

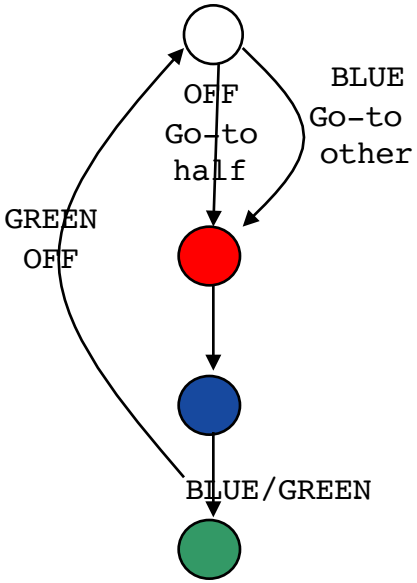
If they both see each other WHITE and they both move all the way to half, gathering is achieved






OFF
Go-to
half
BLUE
Go-to
other
GREEN
OFF
BLUE/GREEN


go-to-half
A
B


OFF
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half
BLUE
Go-to
other
GREEN
OFF
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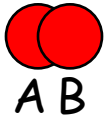
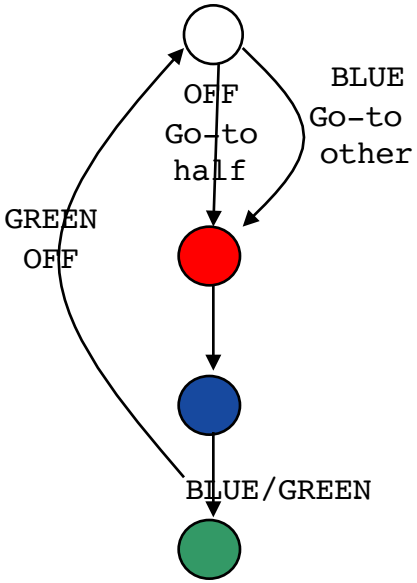
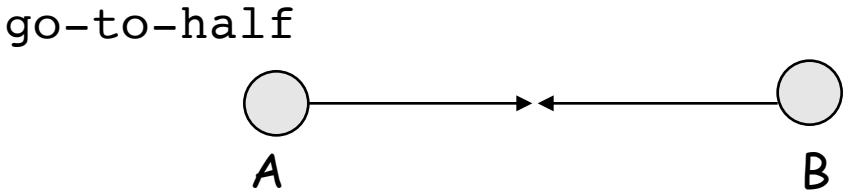
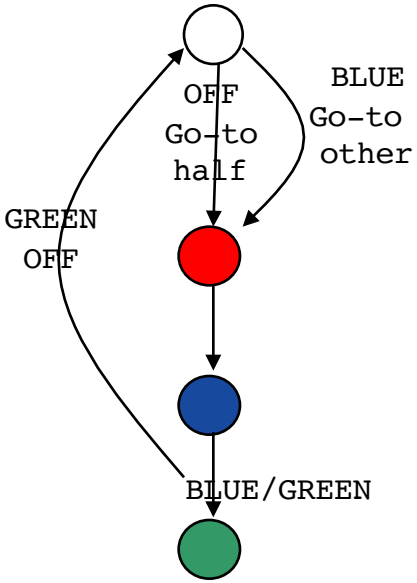

A B

Another scenario






OFF
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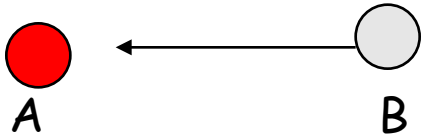
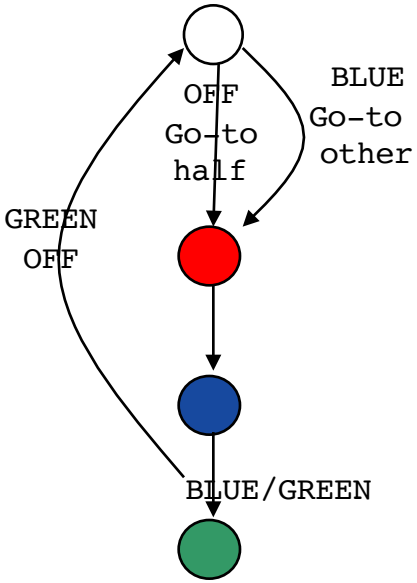
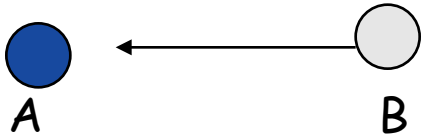
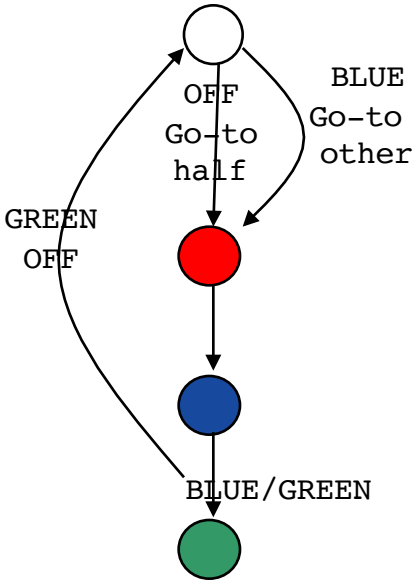
half
BLUE
Go-to
other
GREEN
OFF
BLUE/GREEN

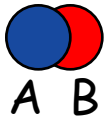

A
B



See blue, go-to-other

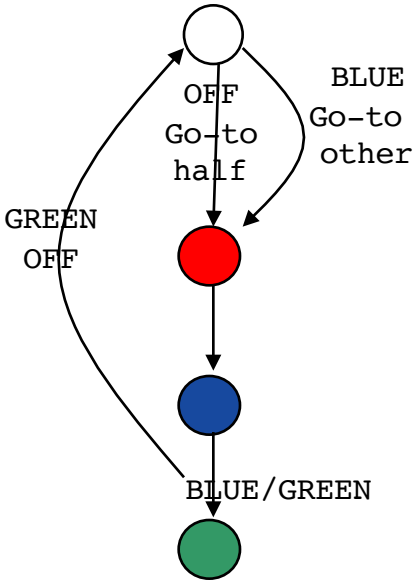


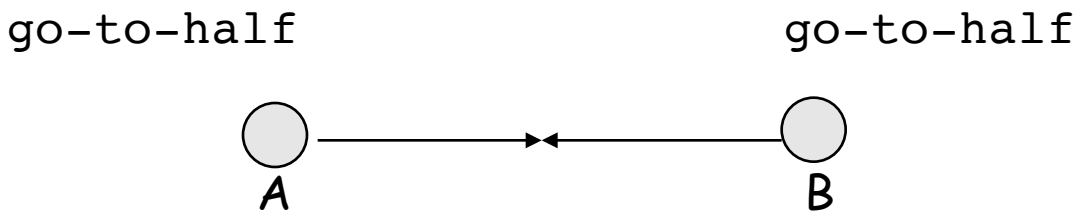

OFF
Go-to
half
BLUE
Go-to
other
GREEN
OFF
BLUE/GREEN

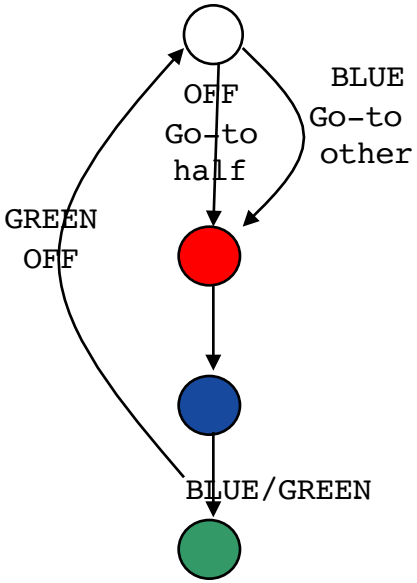

A B

Yet another scenario

(not-rigid)



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other
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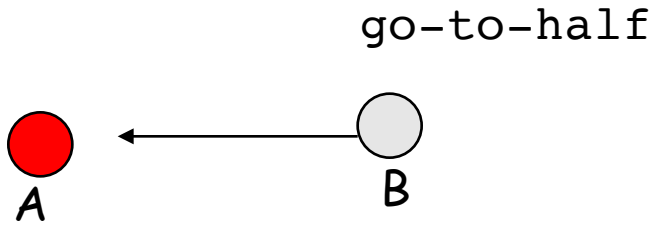
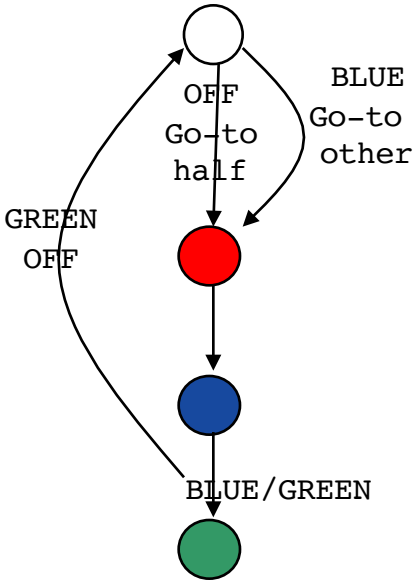
BLUE/GREEN


go-to-half
A
B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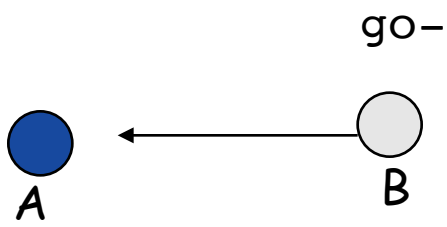
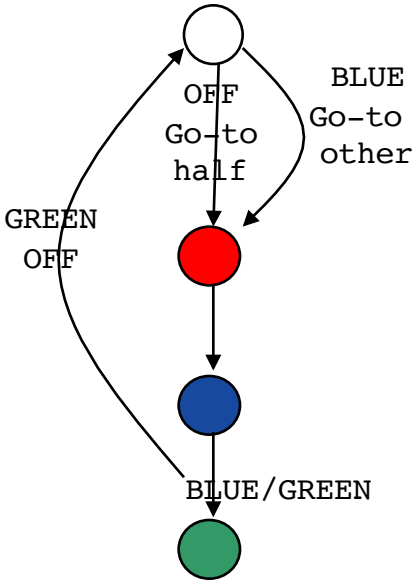

go-to-half
A
B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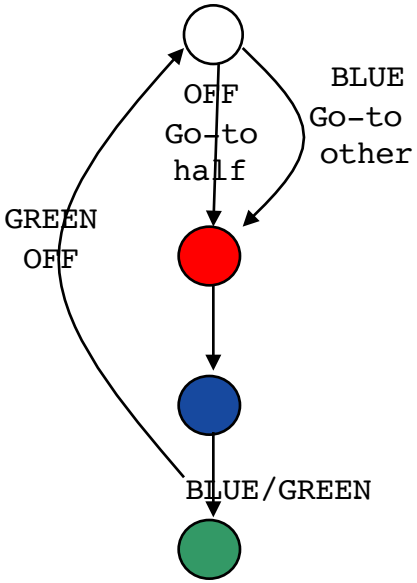
OFF
BLUE/GREEN


A
B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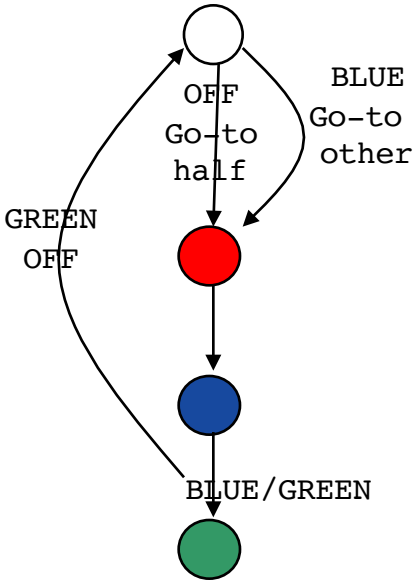
GREEN
OFF
BLUE/GREEN


A
B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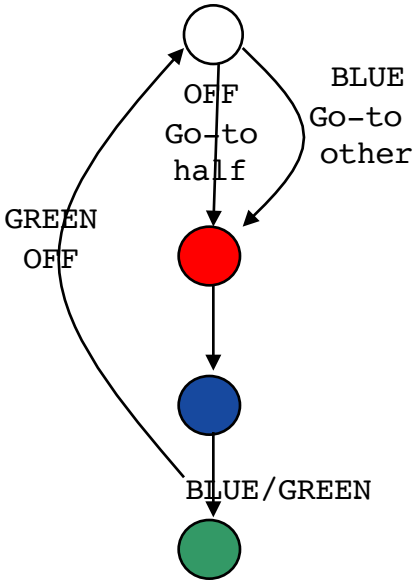
A
B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A
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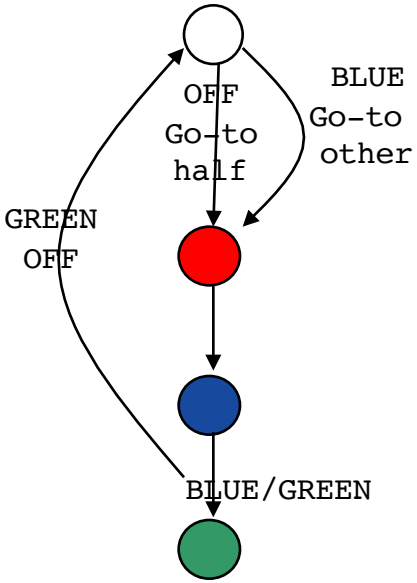


Restarting from a closer distance

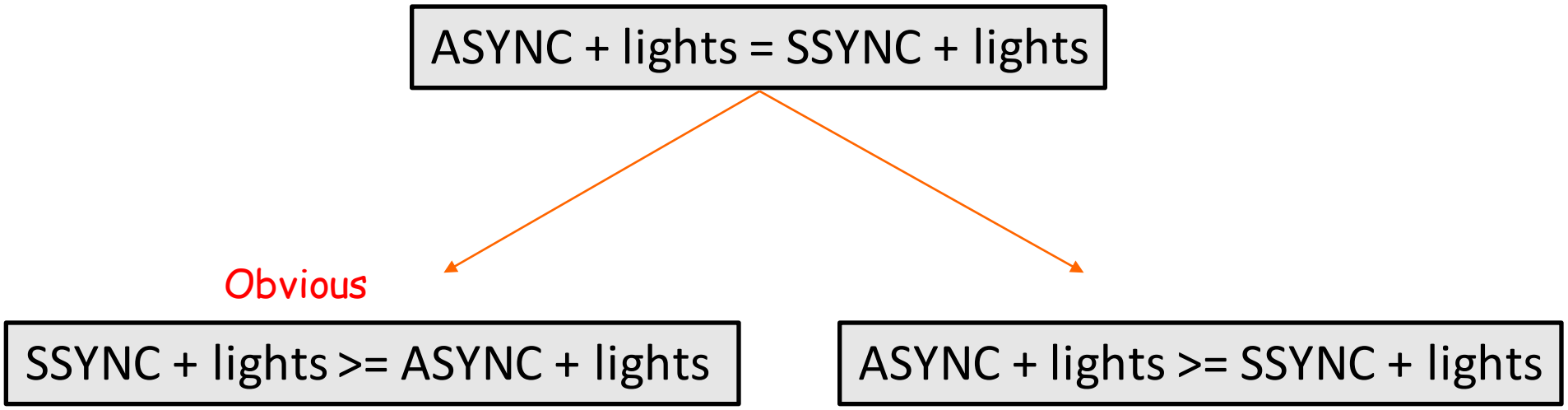
Impact of Lights

3. SSYNC with lights and ASYNC with lights have the same computational power

ASYNC + lights = SSYNC + lights

Impact of Lights

3. SSYNC with lights and ASYNC with lights have the same computational power



Impact of Lights

3. SSYNC with lights and ASYNC with lights have the same computational power

ASYNC + lights = SSYNC + lights

Based on the simulation of SSYNC with ASYNC with 5 lights

ASYNC + lights >= SSYNC + lights

Impact of Lights

4. FSYNC is not more powerful than ASYNC with lights

Oscillating Points problem (OSP): two robots are required to alternately come closer and move further from each other

Impact of Lights

4. FSYNC is not more powerful than ASYNC with lights

Oscillating Points problem (OSP): two robots are required to alternately come closer and move further from each other

FSYNC: the robots cannot distinguish whether they are getting closer or moving further away

Impact of Lights

4. FSYNC is not more powerful than ASYNC with lights

Oscillating Points problem (OSP): two robots are required to alternately come closer and move further from each other

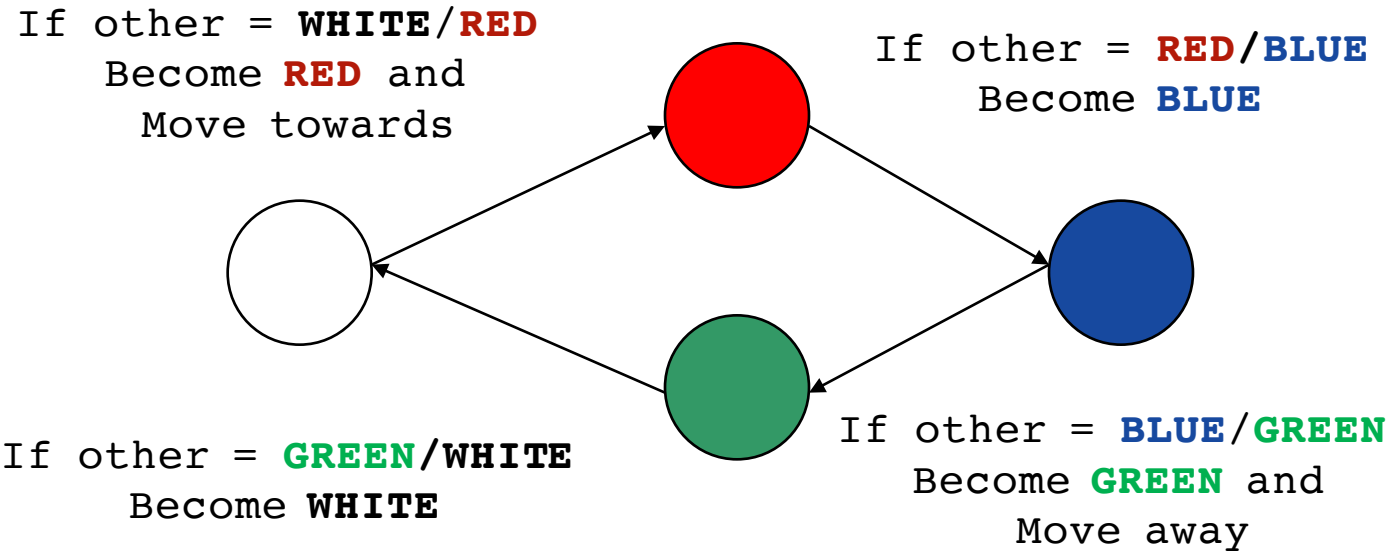
FSYNC: the robots cannot distinguish whether they are getting closer or moving further away

ASYNC: it can be done with 4 lights

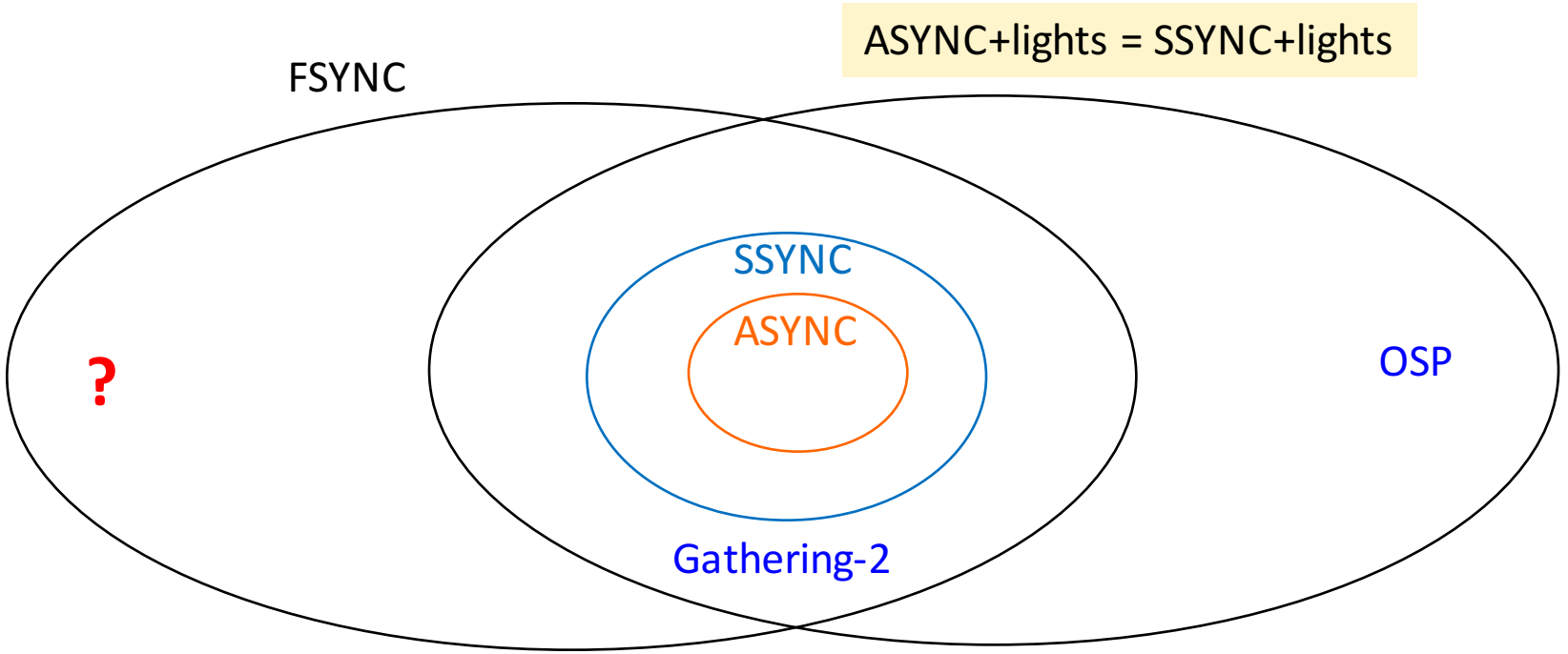
Impact of Lights

4. FSYNC is not more powerful than ASYNC with lights

ASYNC: it can be done with 4 lights



Impact of Lights



Open Problems

Are there problems solvable in FSYNC without lights, but not solvable in ASYNC with lights (i.e., FSYNC and ASYNC with lights orthogonal) ?

Availability of a single snapshot renders ASYNC with lights more powerful than FSYNC without lights. Are there weaker conditions ?

Yes, in discrete

THANK YOU