



Ring exploration with myopic luminous robots

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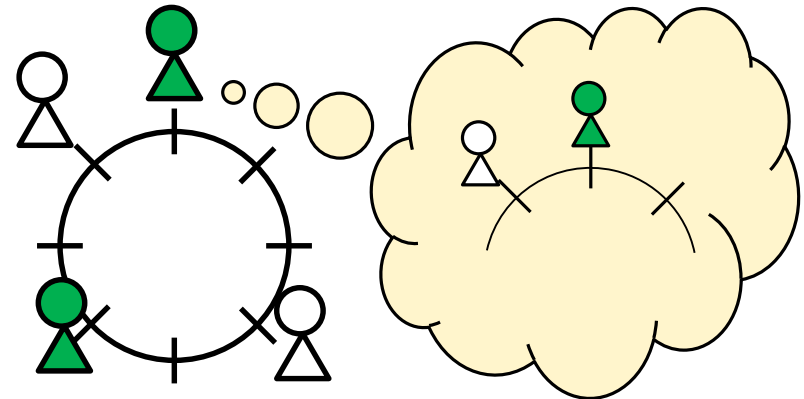
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Summary

- ◆ What is the power of **myopic luminous robots**?
 - Myopia: Robots observe nodes within a fixed distance
 - Luminosity: Robots can emit a single color at a time
- ◆ Perpetual and terminating explorations in rings
 - Algorithms and tight bounds on #robots
 - Visible distance 1
 - 2 colors
 - FSYNC, SSYNC, ASYNC





Outline

- ◆ Background and System Model
- ◆ Our Contributions
- ◆ Ring Explorations
 - FSYNC model
 - SSYNC & ASYNC models
- ◆ Conclusions

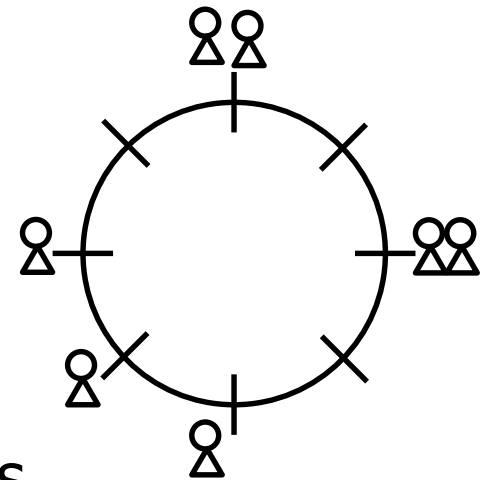
Mobile Robots

◆ Main challenge

- What is the **weakest capability** to solve a given task?

◆ Characteristics of robots

- **Oblivious**: no memory
- **Anonymous**: no ID
- **Deterministic**: no randomization
- **No direct communication**
 - Observe the positions of other robots



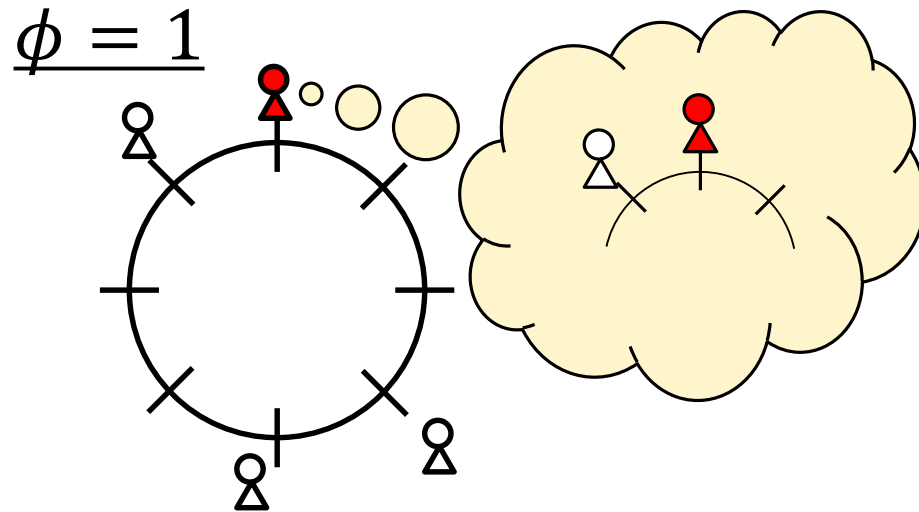
◆ Most works assume **unlimited visibility**

- Robots can observe the global configuration (all robots)

Unlimited visibility seems too powerful

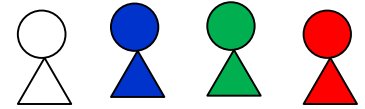
Myopic Robots

- ◆ Robots have **limited visibility**
 - Observe nodes **within distance ϕ**
- ◆ Solvable tasks are very limited if $\phi = 1$
 - Exploration is **impossible**
in the semi-synchronous and asynchronous models [1]



[1] A. K. Datta, A. Lamani, L. L. Larmore, and F. Petit, "Ring exploration by oblivious agents with local vision," ICDCS 2013

Luminous Robots

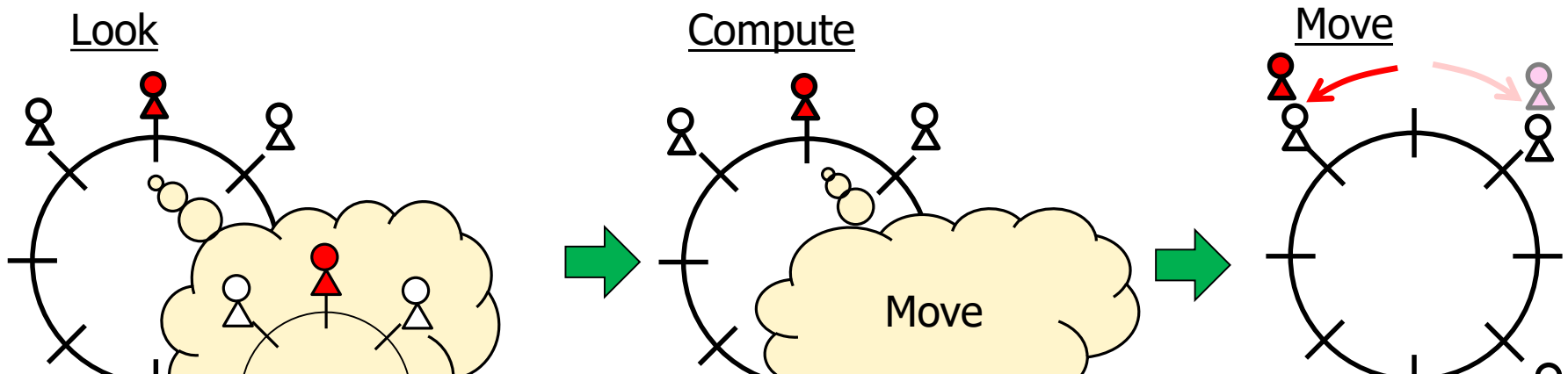


- ◆ Robots endowed with **lights**
 - Light can emit κ **colors**, a single color at a time
 - Light is **non-volatile** and **visible to all robots** (full-light)
- ◆ The impact of lights on non-myopic robots
 - Asynchronous robots with lights can achieve the same task as semi-synchronous robots [2]

What is the impact of lights
on exploration of myopic robots?

Execution of Robots

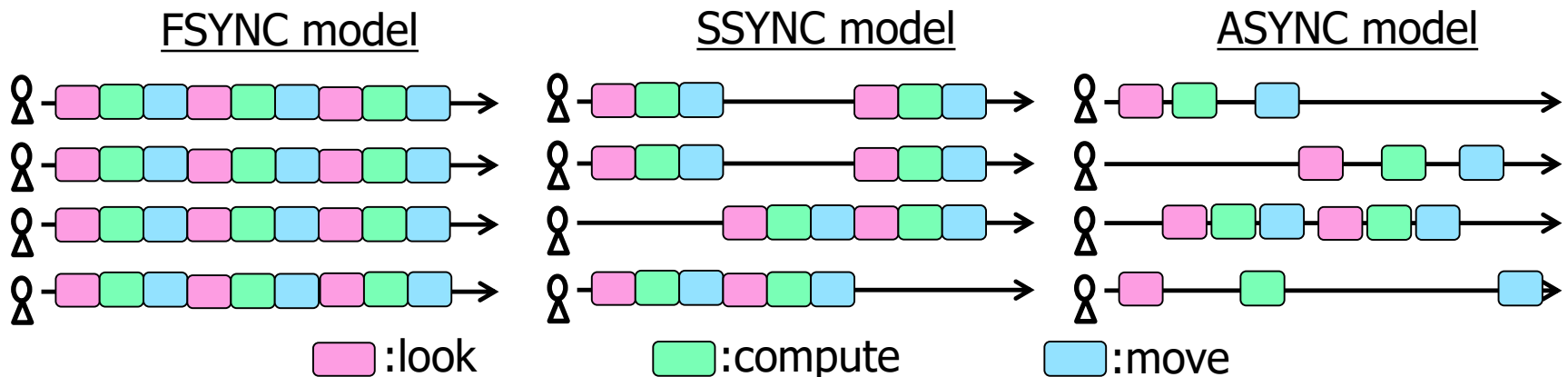
- ◆ Each robot repeats **look-compute-move** cycles
 - **Looks** at a configuration within distance ϕ
 - **Computes** its next color and movement
 - Changes its color if necessary
 - **Moves** to the computed direction
 - Reaches its neighbor **instantaneously** if it moves



If the view is symmetric, the robot cannot decide direction

Synchrony

- ◆ **FSYNC (fully synchronous) model**
 - Cycles of **all robots** are executed **synchronously**
- ◆ **SSYNC (semi-synchronous) model**
 - A **set** of activated robots is selected by a scheduler
 - Cycles of activated robots are executed **synchronously**
- ◆ **ASYNC (asynchronous) model**
 - Cycles of robots are executed **asynchronously**



Ring Exploration

◆ Perpetual exploration

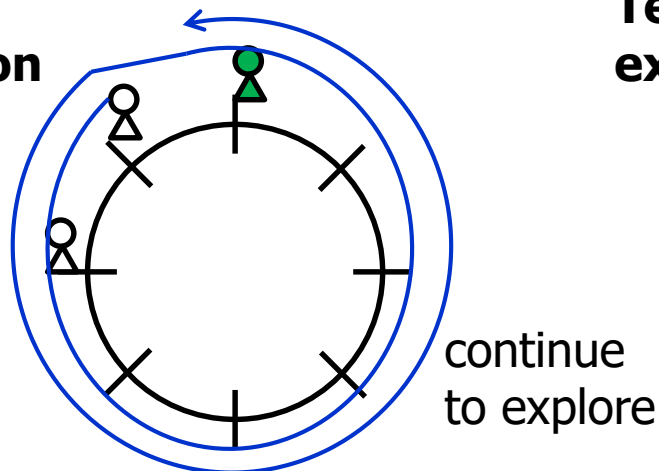
- Each node is visited by some robots infinite times

◆ Terminating exploration

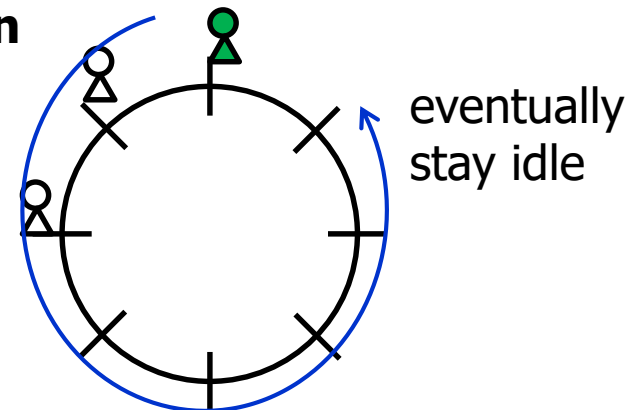
- Each node is visited by at least one robot
- Robots eventually stay idle

What is the minimum #robots?

**Perpetual
exploration**



**Terminating
exploration**





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Our Contributions (1)

ϕ : Visible distance
 κ : #colors

- ◆ FSYNC with $\phi = 1$ and $\kappa = 2$
 - Perpetual exploration
 - **Two** robots are necessary and sufficient
 - Terminating exploration
 - **Three** robots are necessary and sufficient

Results on FSYNC

	Exploration	Visible distance	Light	#robots	
				Necessary	Sufficient
[3]	Terminating	1	No	5	5
Our work	Perpetual	1	2 colors	2	2
Our work	Terminating	1	2 colors	3	3

[3] A. K. Datta, A. Lamani, L. L. Larmore, and F. Petit, "Ring exploration by oblivious agents with local vision," ICDCS 2013

Our Contributions (2)

ϕ : Visible distance
 κ : #colors

- ◆ **SSYNC & ASYNC with $\phi = 1$ and $\kappa = 2$**
 - Perpetual exploration
 - **Three** robots are necessary and sufficient
 - Terminating exploration
 - **Four** robots are necessary and sufficient

Results on SSYNC & ASYNC

	Exploration	Visible distance	Light	#robots	
				Necessary	Sufficient
[3]	Terminating	1	No	Impossible	
[4]	Terminating	2	No	5	7
[4]	Terminating	3	No	5	5
Our work	Perpetual	1	2 colors	3	3
Our work	Terminating	1	2 colors	4	4

Our Contributions (3)

ϕ : Visible distance
 κ : #colors

- ◆ All of our algorithms start from some designated initial configurations
- ◆ Our algorithms for perpetual exploration are **universal** in case of $\phi = 1$ and $\kappa = 2$
 - A universal algorithm solves the problem from any solvable initial configuration
- ◆ **No universal algorithm** exists for terminating exploration in case of $\phi = 1$ and $\kappa = 2$

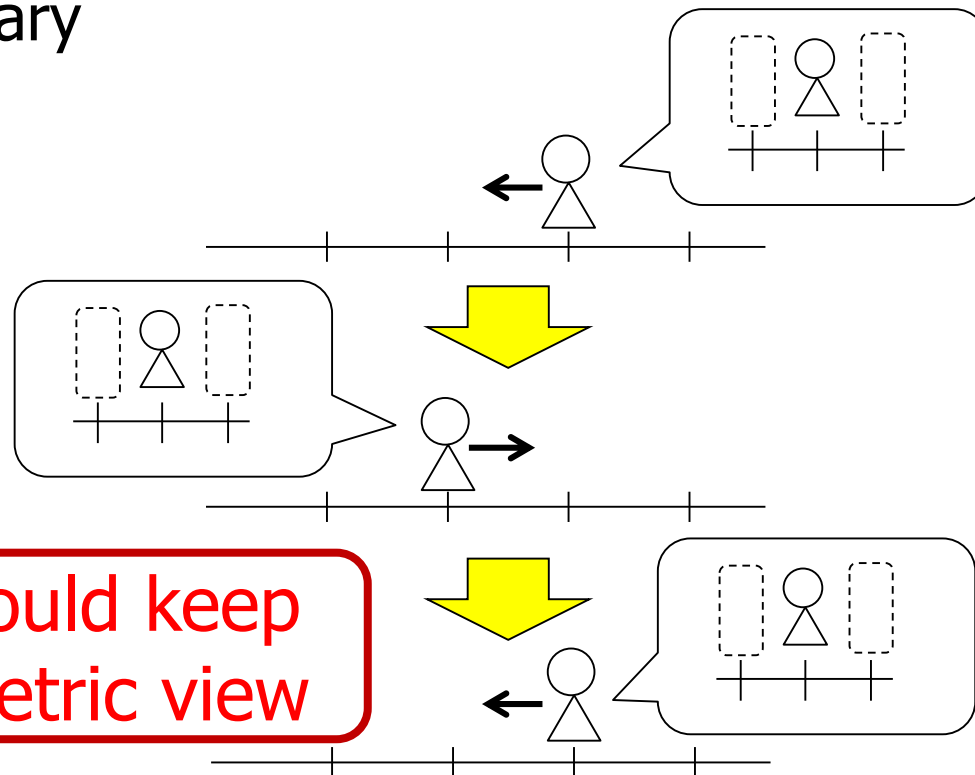


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Perpetual Exp. in FSYNC

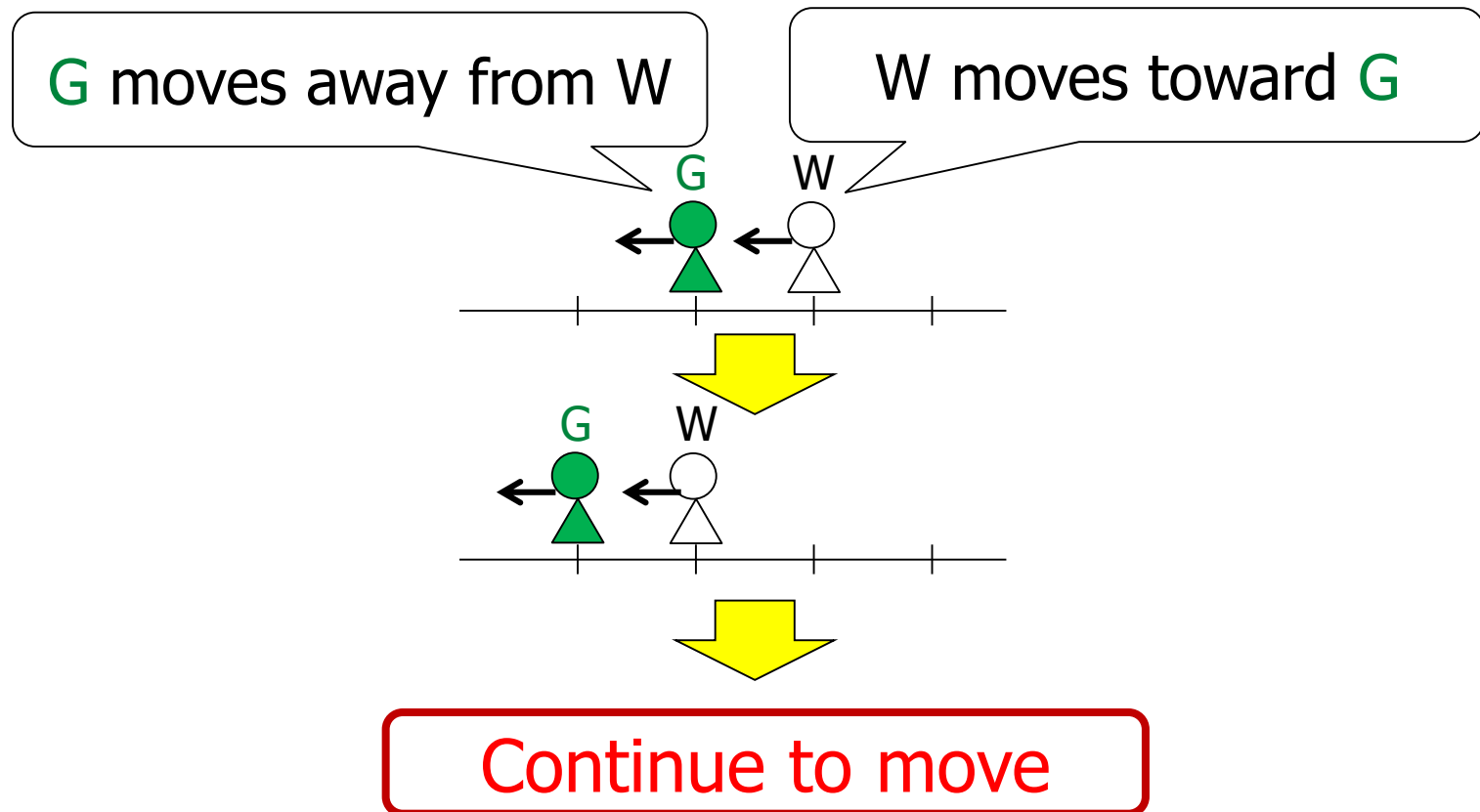
- ◆ One robot cannot achieve perpetual exploration
 - The local view of the robot is always symmetric
 - The direction of its movement is decided by the adversary



Robots should keep non-symmetric view

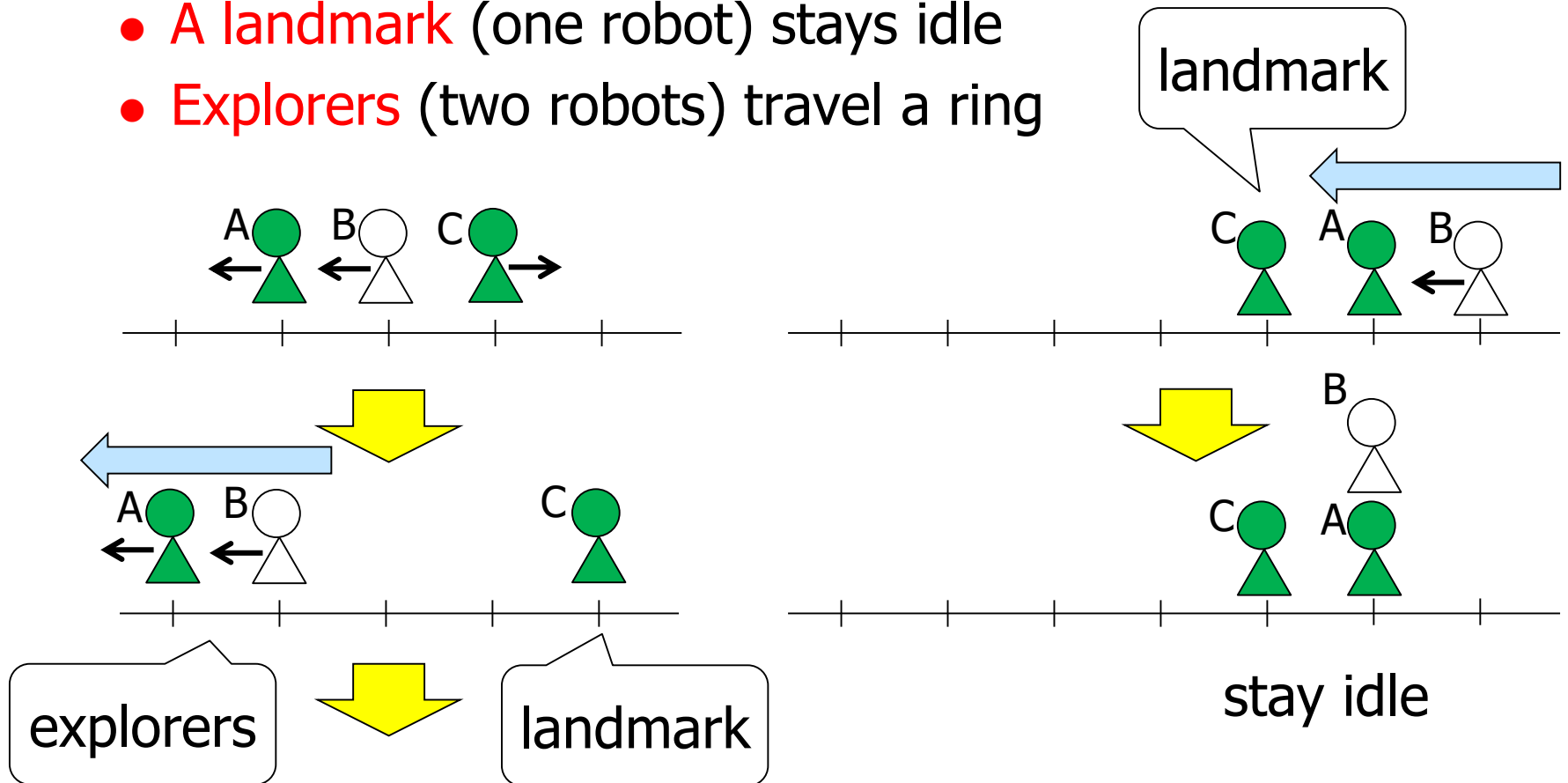
Perpetual Exp. in FSYNC

- ◆ Two robots can achieve perpetual exploration
 - Color: G (green) , W (white) 



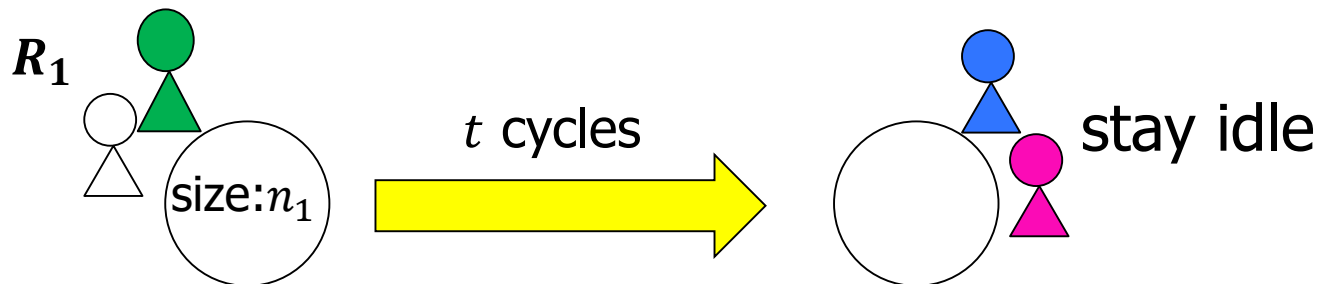
Terminating Exp. in FSYNC

- ◆ Three robots can achieve terminating exploration
 - Divide robots into two groups
 - A **landmark** (one robot) stays idle
 - **Explorers** (two robots) travel a ring



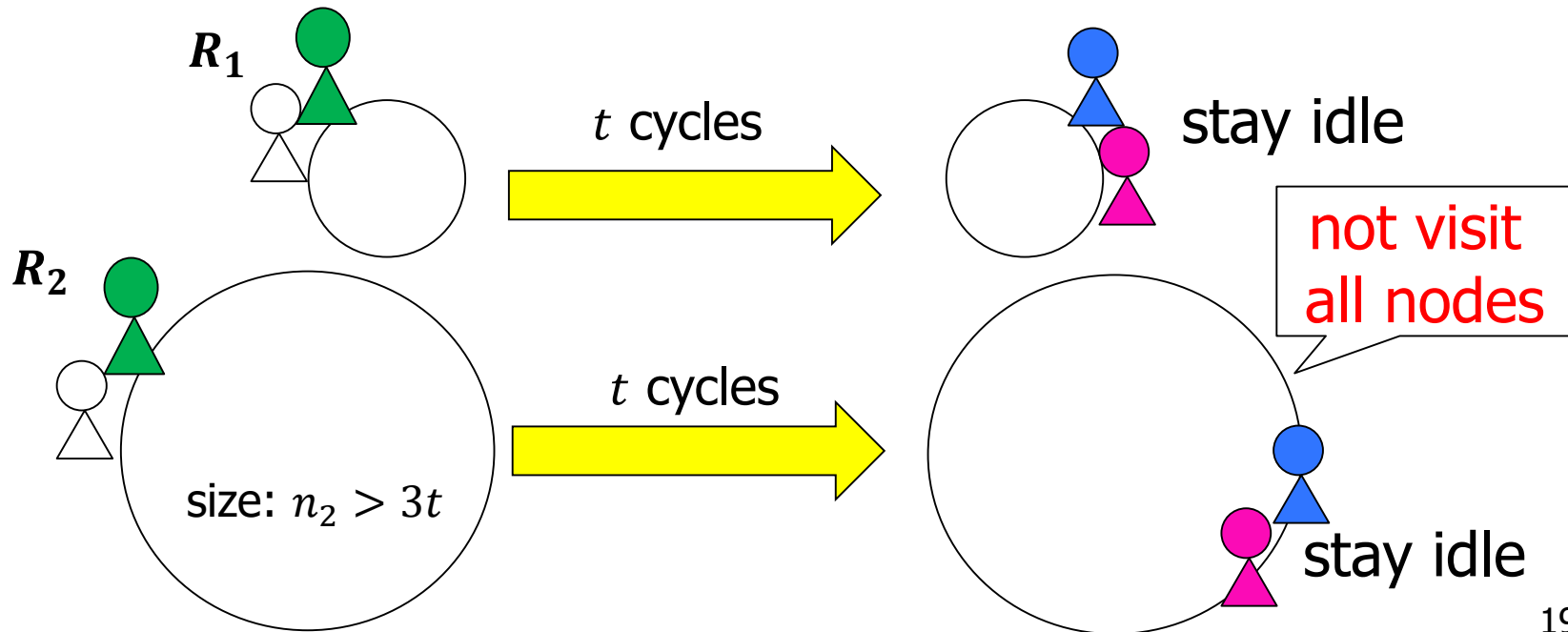
Impossibility of Two Robots (1/3)

- ◆ Two robots cannot achieve terminating exploration
 - Even if the number of colors is infinite
- ◆ Proof
 - Assume such algorithm exists for contradiction
 - Consider a n_1 -node ring R_1
 - Two robots will achieve terminating exploration after t cycles



Impossibility of Two Robots (2/3)

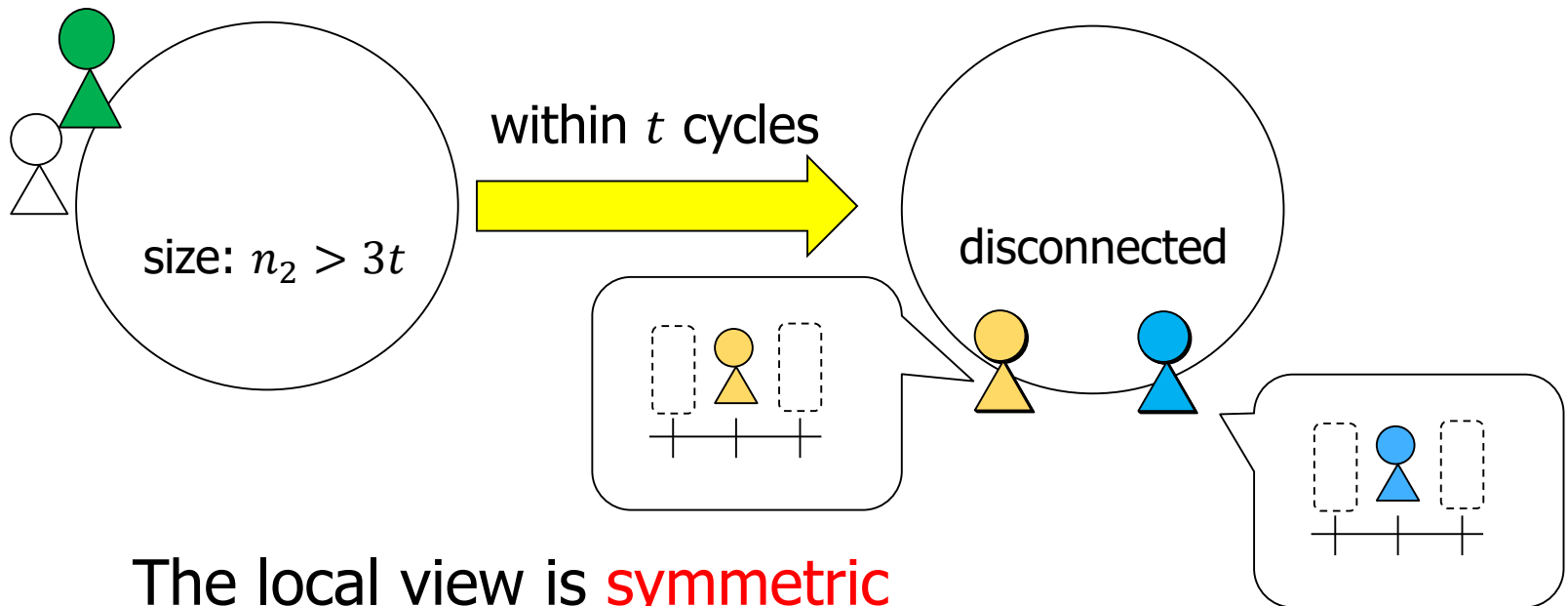
- ◆ Consider a very big n_2 -node ring R_2 ($n_2 > 3t$)
 - Robots cannot visit all nodes within t cycles
- ◆ Case 1: Two robots are always connected
 - They cannot recognize difference between R_1 and R_2
 - They terminate in t cycles \rightarrow cannot visit some nodes



Impossibility of Two Robots (3/3)

- ◆ Case 2: Two robots become disconnected
 - They cannot visit some nodes

Contradiction!



The local view is **symmetric**

The adversary decides the direction of the movement

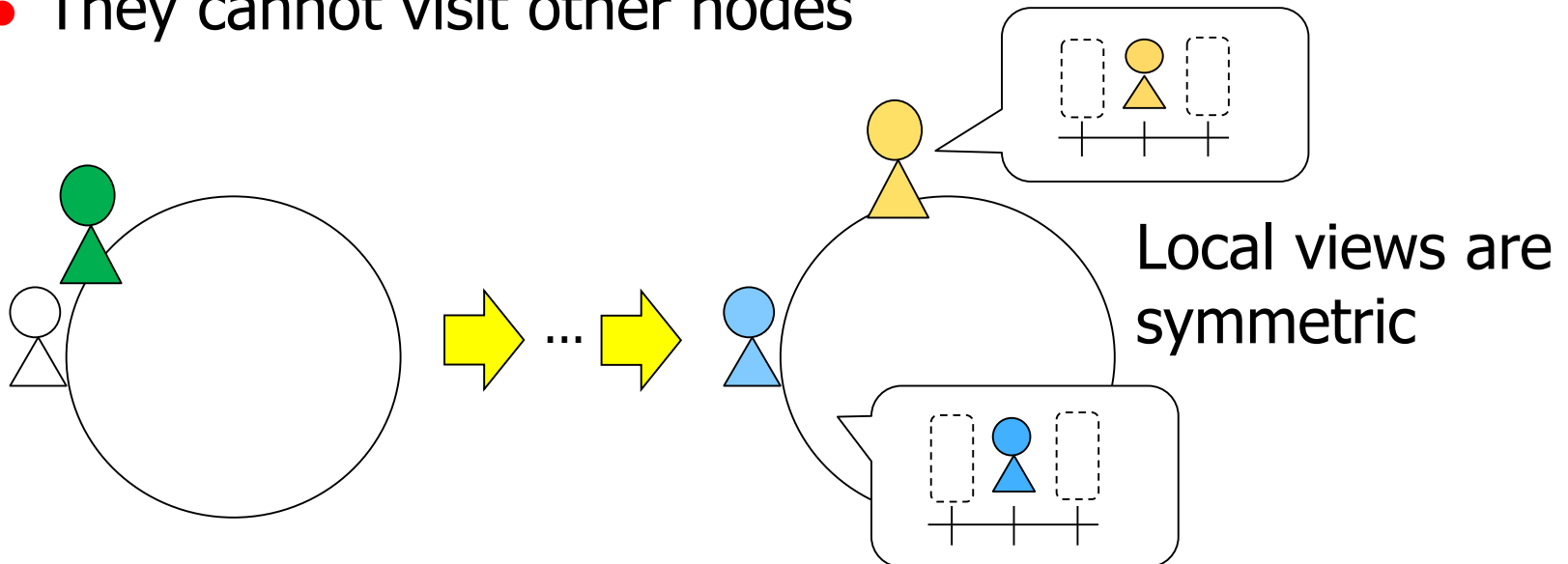


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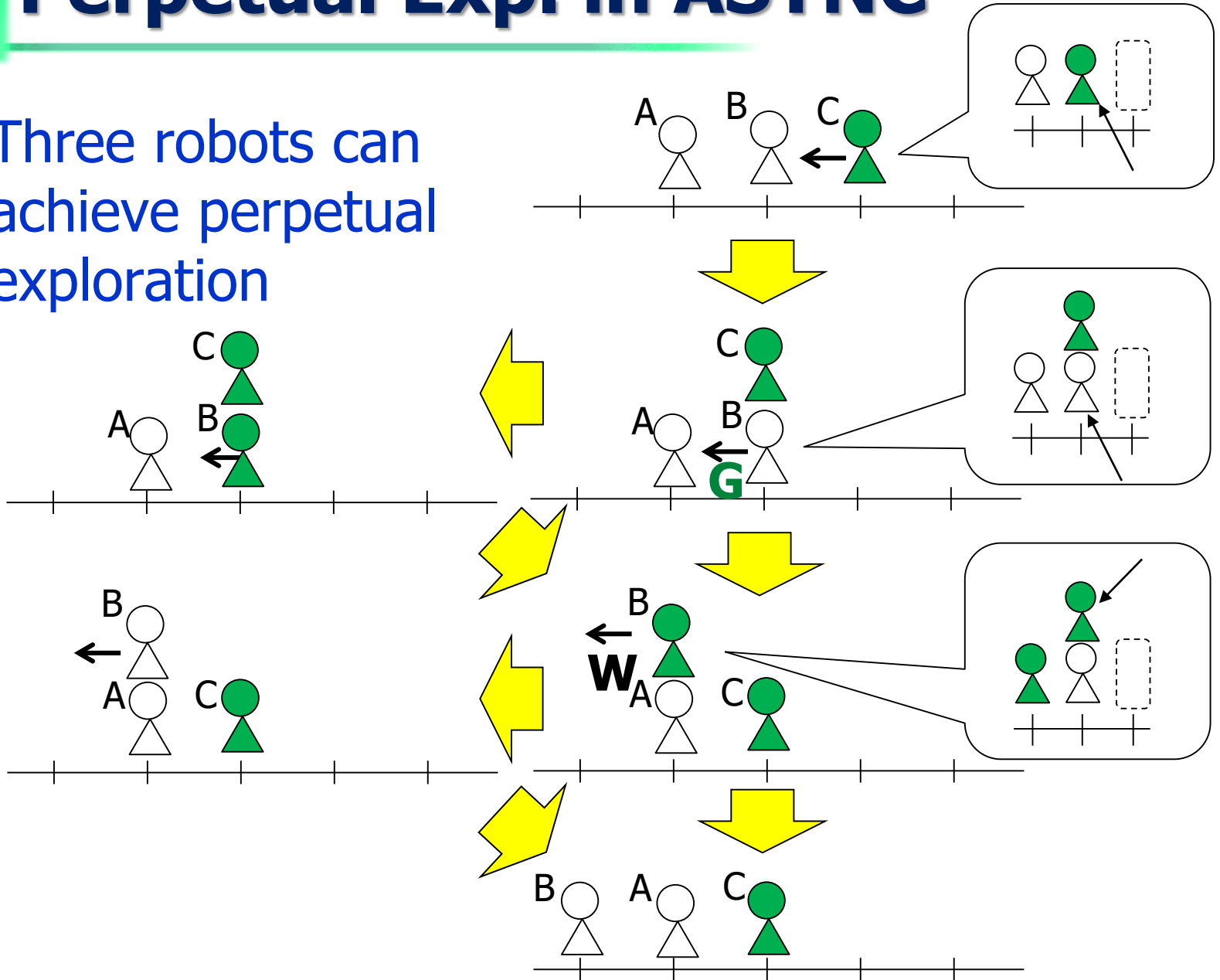
Perpetual Exp. in SSYNC

- ◆ Two robots cannot achieve perpetual exploration
 - Even if the number of colors is infinite
- ◆ Proof
 - The adversary moves robots one by one
 - Eventually robots become disconnected
 - They cannot visit other nodes



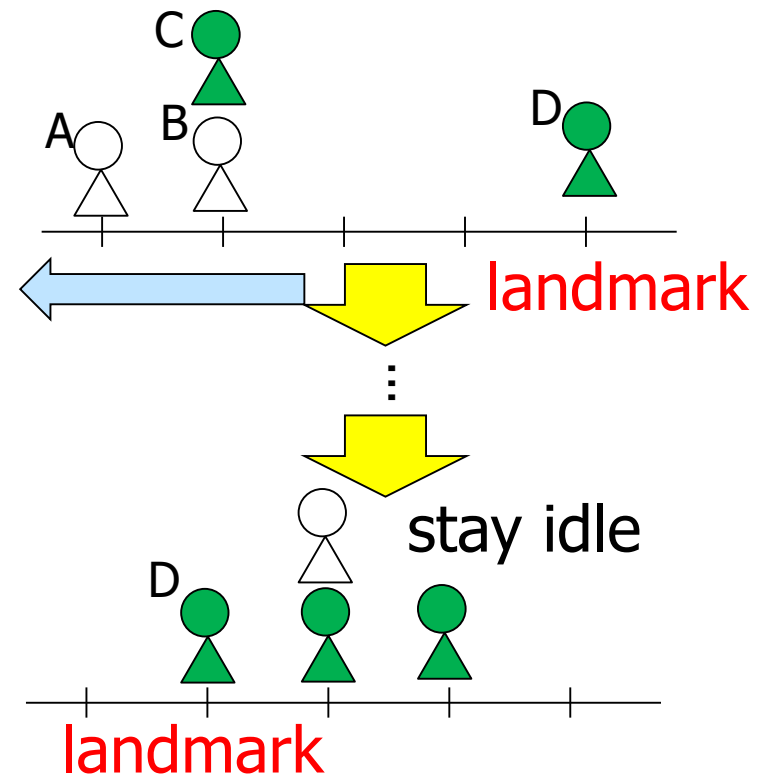
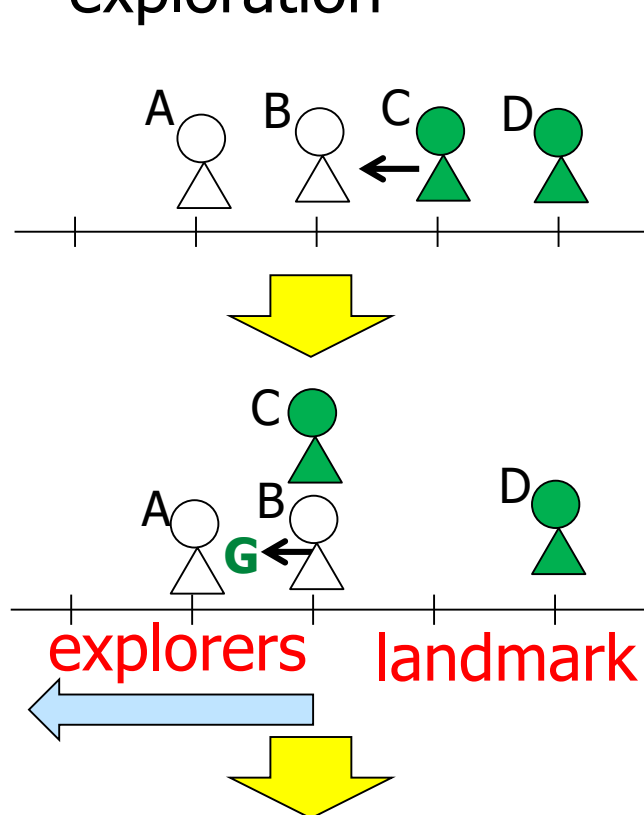
Perpetual Exp. in ASYNC

- ◆ Three robots can achieve perpetual exploration



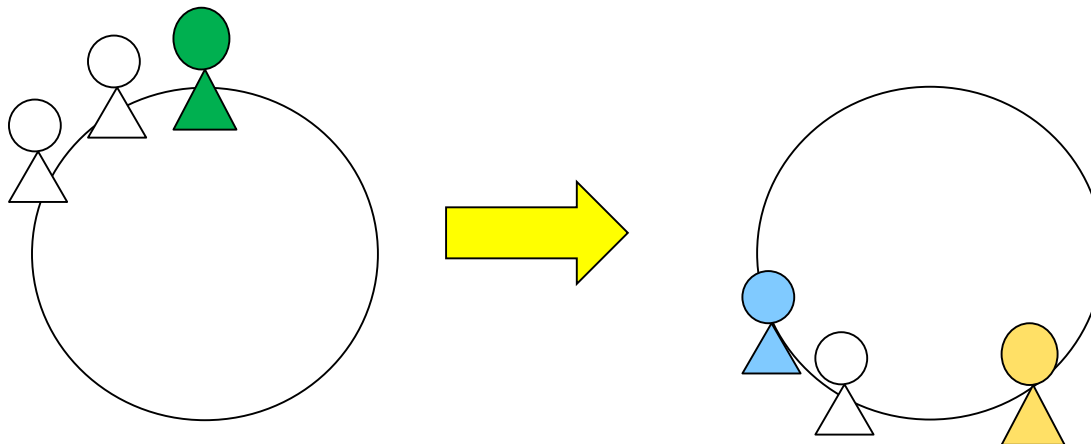
Terminating Exp. in ASYNC

- ◆ Four robots can achieve terminating exploration
 - A **landmark** (one robot) stays idle
 - **Explorers** (three robots) travel a ring by perpetual exploration



Terminating Exp. in SSYNC

- ◆ Three robots cannot achieve terminating exploration
 - Even if the number of colors is infinite
- ◆ Proof
 - Similar to FSYNC
 - If three robots become disconnected, they cannot travel a ring



Conclusions

◆ Ring exploration of myopic luminous robots

	Exploration	Visibility	Light	#robots	
				Necessary	Sufficient
FSYNC	Perpetual	1	2 colors	2	2
FSYNC	Terminating	1	2 colors	3	3
SSYNC&ASYNC	Perpetual	1	2 colors	3	3
SSYNC&ASYNC	Terminating	1	2 colors	4	4

◆ Open problems

- Are computational powers of myopic luminous robots different between SSYNC and ASYNC?
- Is there some trade-off between visibility and #colors?