POLITECNICO DI MILANO

AN ANALYSIS OF COORDINATION MECHANISMS FOR MULTI-ROBOT EXPLORATION OF INDOOR ENVIRONMENTS

Marco Cattaneo

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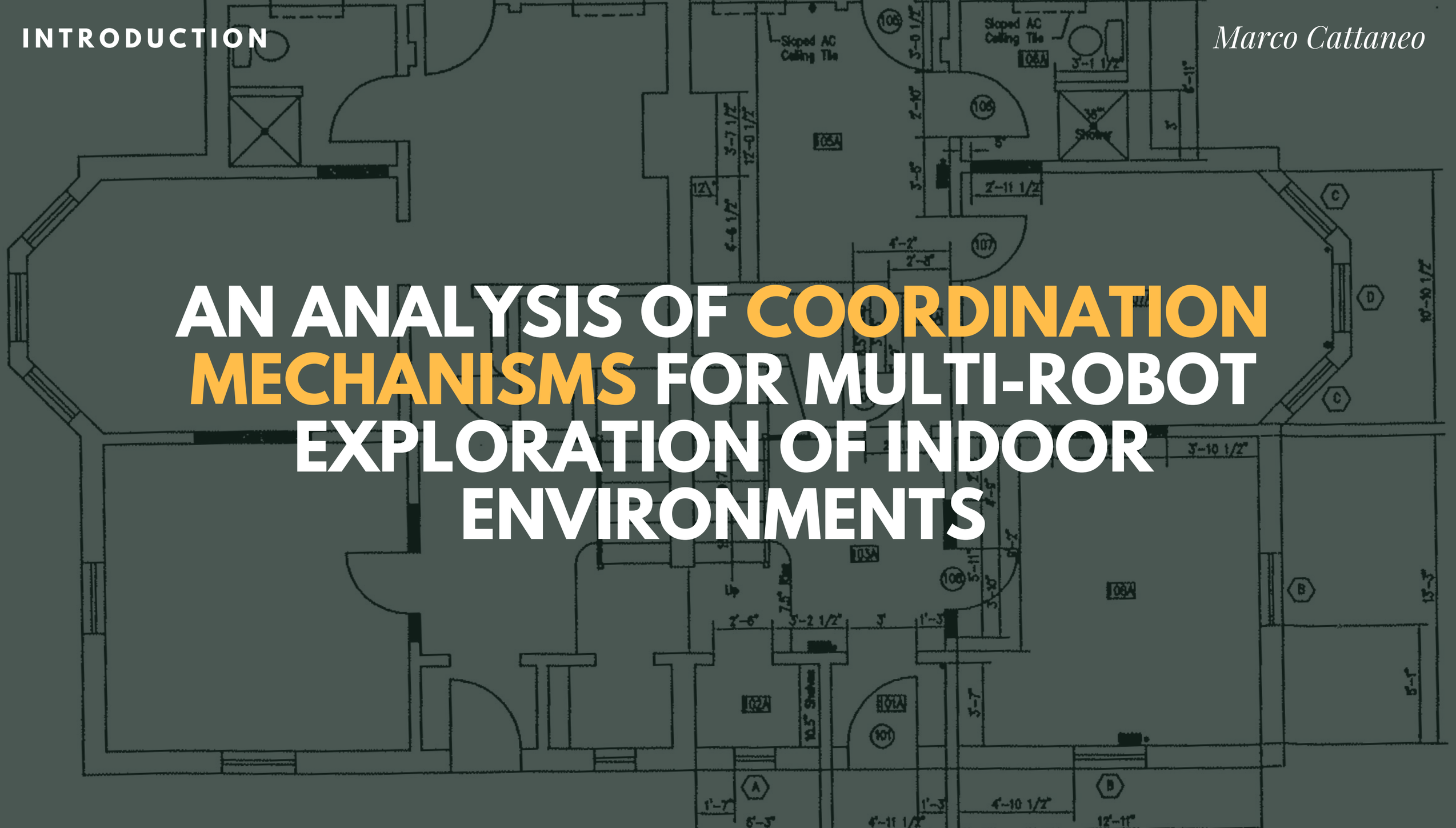

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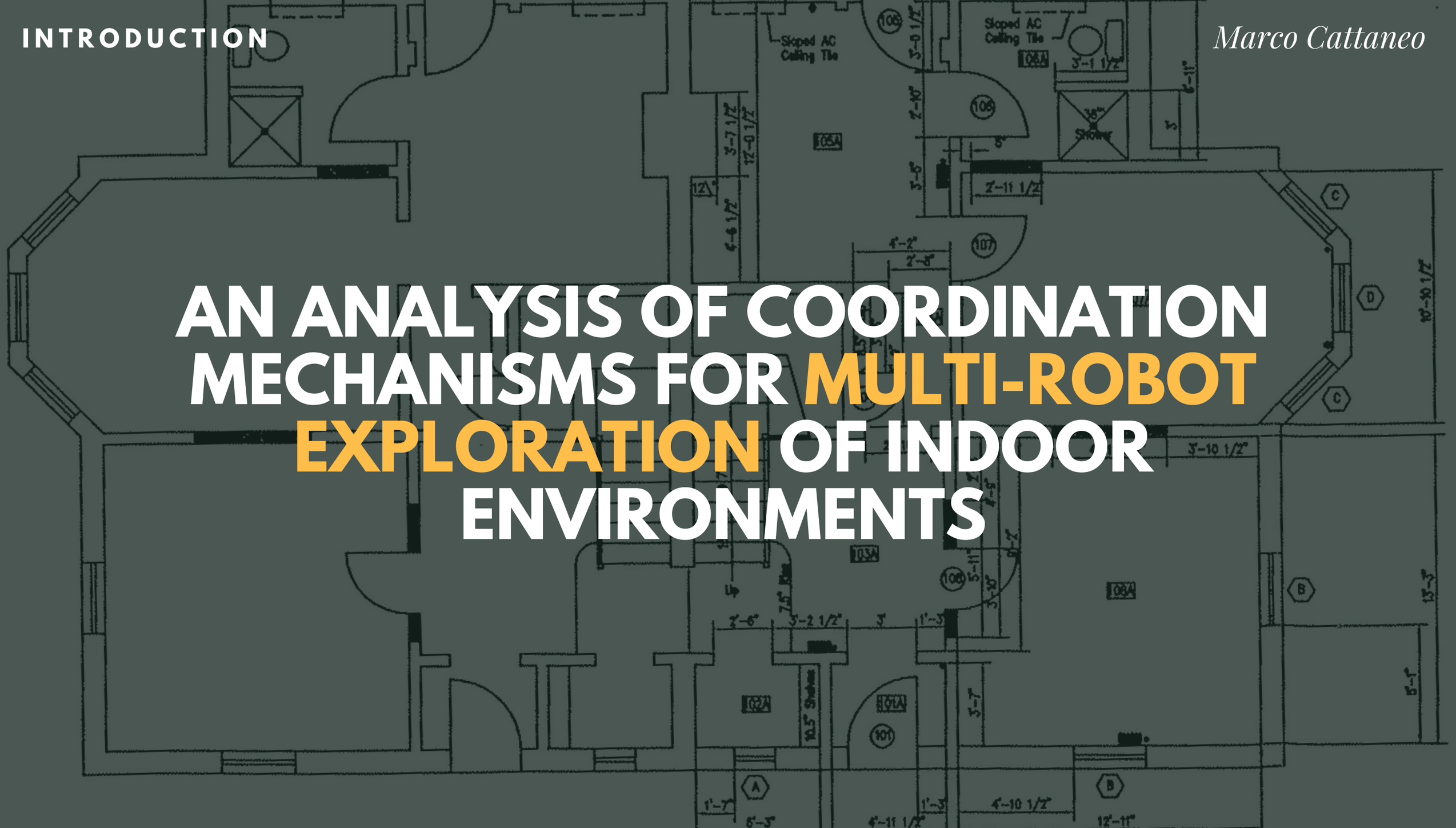

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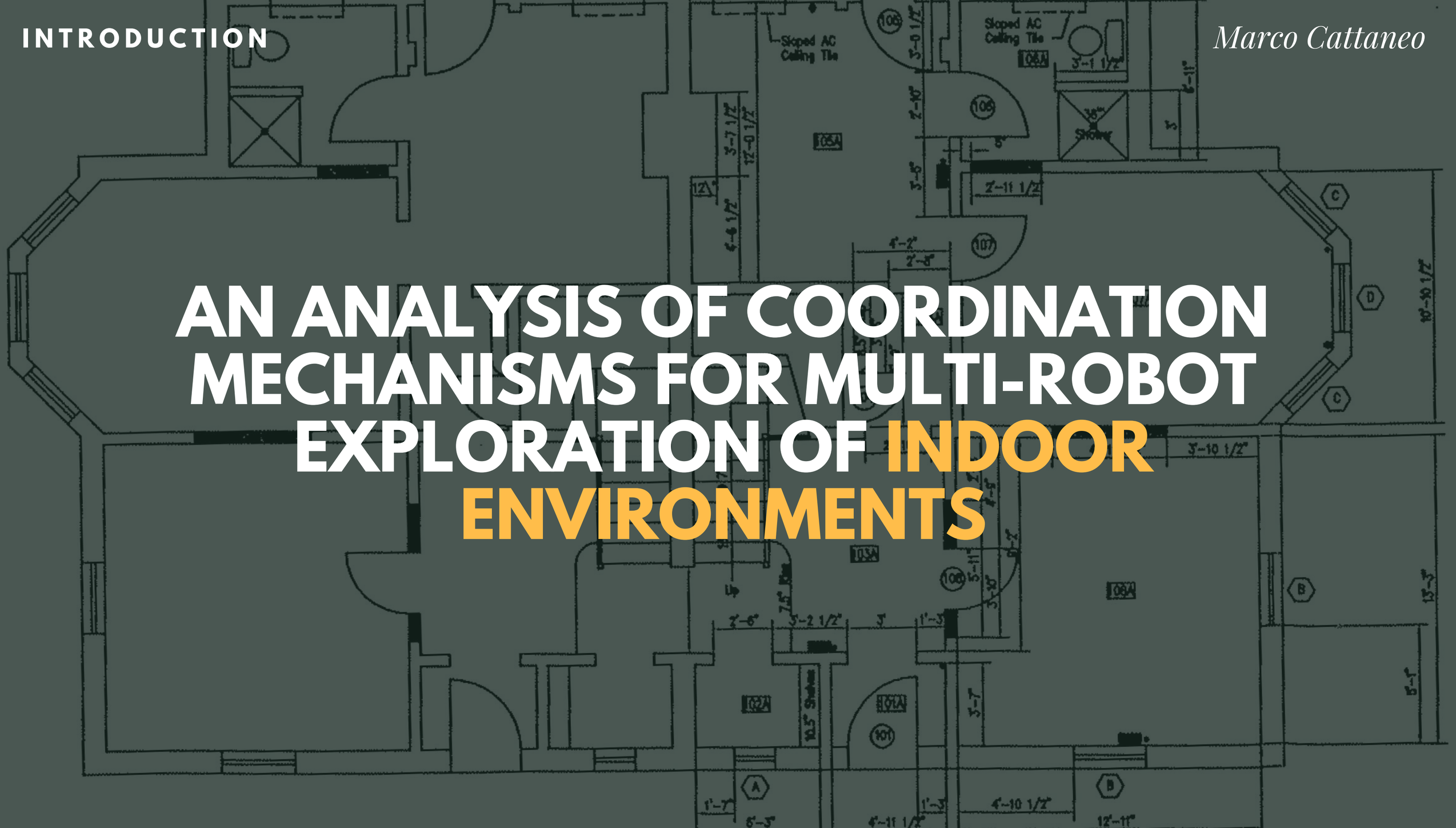

AN ANALYSIS OF COORDINATION MECHANISMS FOR MULTI-ROBOT EXPLORATION OF INDOOR ENVIRONMENTS

STATE OF THE ART

EXPLORATION STRATEGIES

Where to go next?

B. YAMAUCHI, 1998

COORDINATION MECHANISMS

STATE OF THE ART

EXPLORATION STRATEGIES

Where to go next?

B. YAMAUCHI, 1998

COORDINATION MECHANISMS

Who goes where?

STATE OF THE ART

COORDINATION MECHANISMS

Who goes where?

ONLINE COORDINATION

Coordinate through dynamically considering current agents actions

W. BURGARD ET AL., 2000/2005

OFFLINE COORDINATION

Coordinate through statically assigning roles to agents

H. CHRISTENSEN ET AL., 2014

WHAT IS THE PROBLEM?

Practical

FEW COORDINATION MECHANISMS WHERE TESTED

Practical

ONLINE AND OFFLINE CONTRIBUTIONS WERE NOT STUDIED IN DEPTH

Theoretical

NO FORMAL FRAMEWORK WAS PROPOSED

GOAL OF THE THESIS

Practical

DEVELOP AND TEST DIFFERENT COORDINATION MECHANISMS

Practical

EVALUATE ONLINE AND OFFLINE CONTRIBUTIONS

Theoretical

PROPOSE A FORMAL FRAMEWORK TO DESCRIBE COORDINATION MECHANISMS

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PROBLEM SETTING

Robot configuration

GROUND ROBOTS, SENSING WITH A LASER RANGE SCANNER

Environments

Exploration strategy

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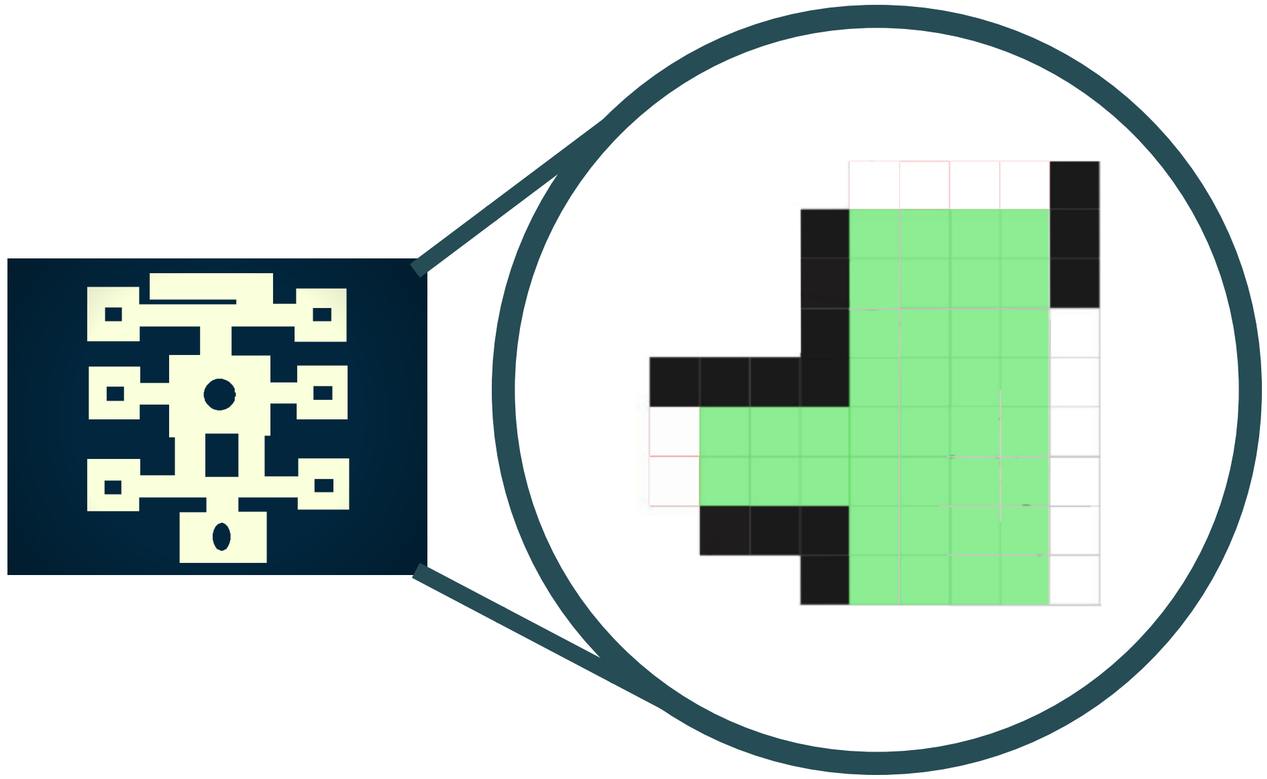
PROBLEM SETTING

Robot configuration

Environments

2D ENVIRONMENTS REPRESENTED BY OCCUPANCY GRIDMAPS



Exploration strategy

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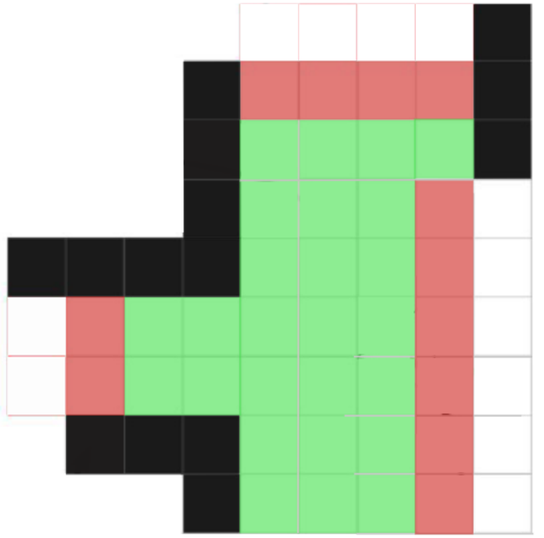
PROBLEM SETTING

Robot configuration

Environments

Exploration strategy

FRONTIER-BASED STRATEGY



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FORMAL FRAMEWORK

EXPLORATION STATE

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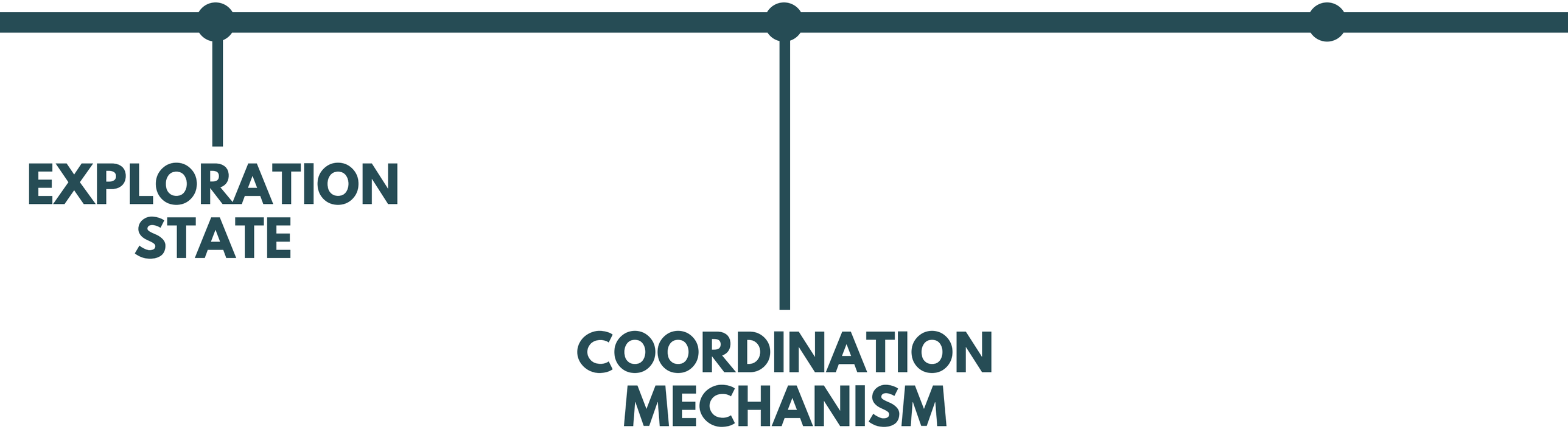
FORMAL FRAMEWORK



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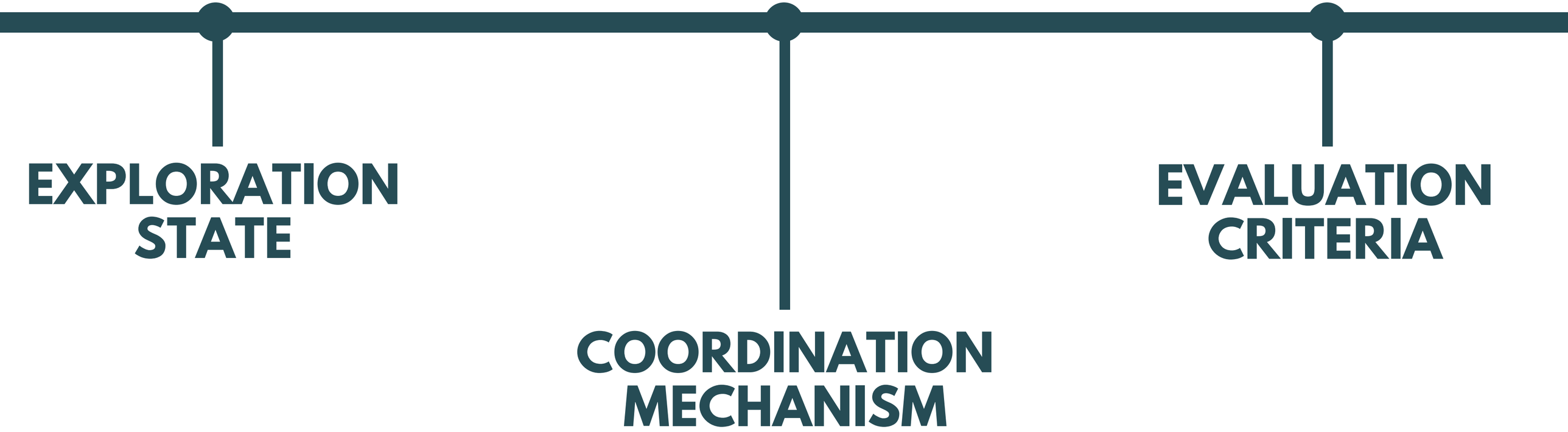
FORMAL FRAMEWORK



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EXPLORATION STATE

IT COLLECTS THE INFORMATION AGENTS HAVE AT EACH STEP OF THE EXPLORATION

KNOWN AREA K(t)

Area known by the agents at time t

AGENTS' POSES P(t)

AGENTS' GOALS G(t)

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EXPLORATION STATE

IT COLLECTS THE INFORMATION AGENTS HAVE AT EACH STEP OF THE EXPLORATION

AREA KNOWN K(t)

Area known by the agents at time t

AGENTS' POSES P(t)

Agents' poses and orientations at time t

AGENTS' GOALS G(t)

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EXPLORATION STATE

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AREA KNOWN K(t)

Area known by the agents at time t

AGENTS' POSES P(t)

Agents' poses and orientations at time t

AGENTS' GOALS G(t)

Frontiers assigned to agents at time t

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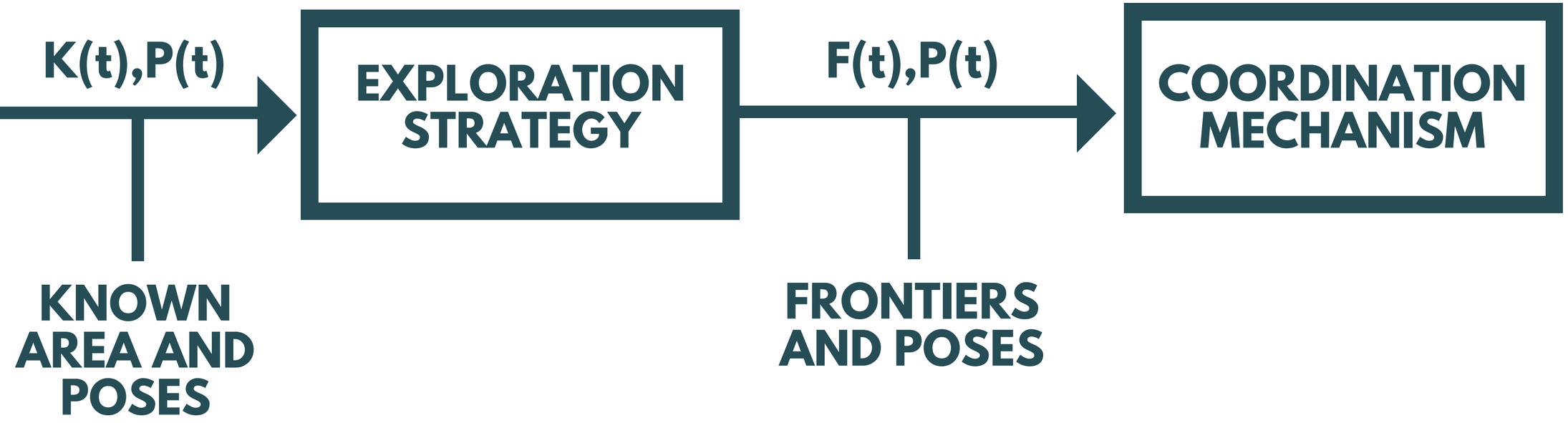
COORDINATION MECHANISM

IT ASSIGNS A GOAL LOCATION TO EVERY AGENT AT EACH STEP OF THE EXPLORATION



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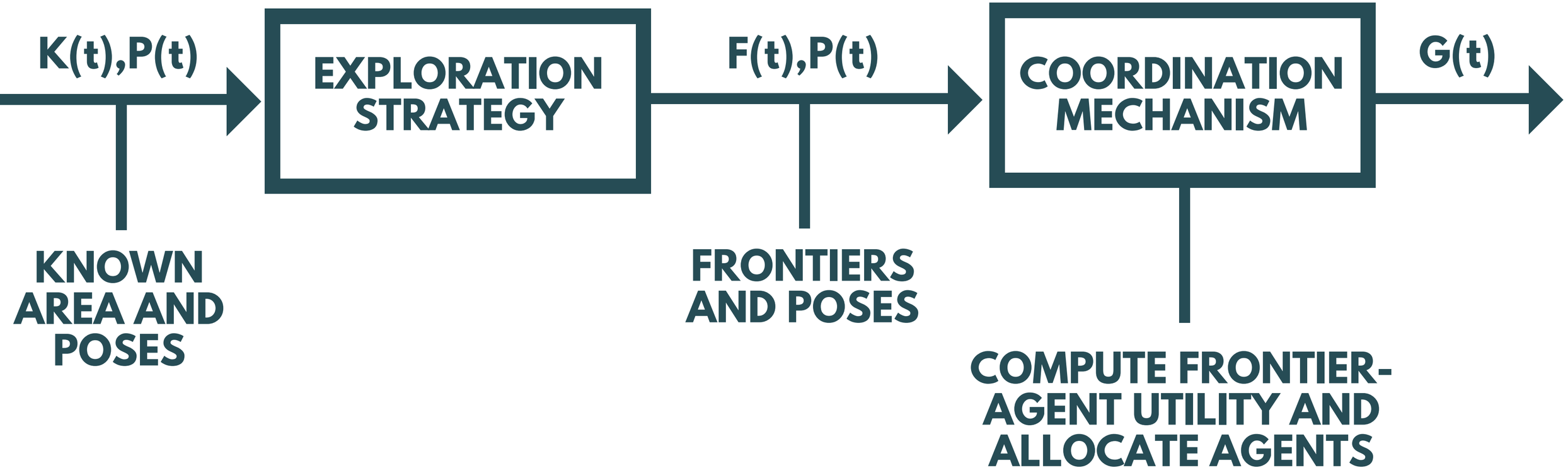


$$e.g., u(a,f) = I(f) - d(a,f)$$

EVALUATION CRITERIA

TWO MEASURES USEFUL TO COMPARE COORDINATION MECHANISMS

Interference

AVERAGE DISTANCE BETWEEN THE AGENTS

Availability

EVALUATION CRITERIA

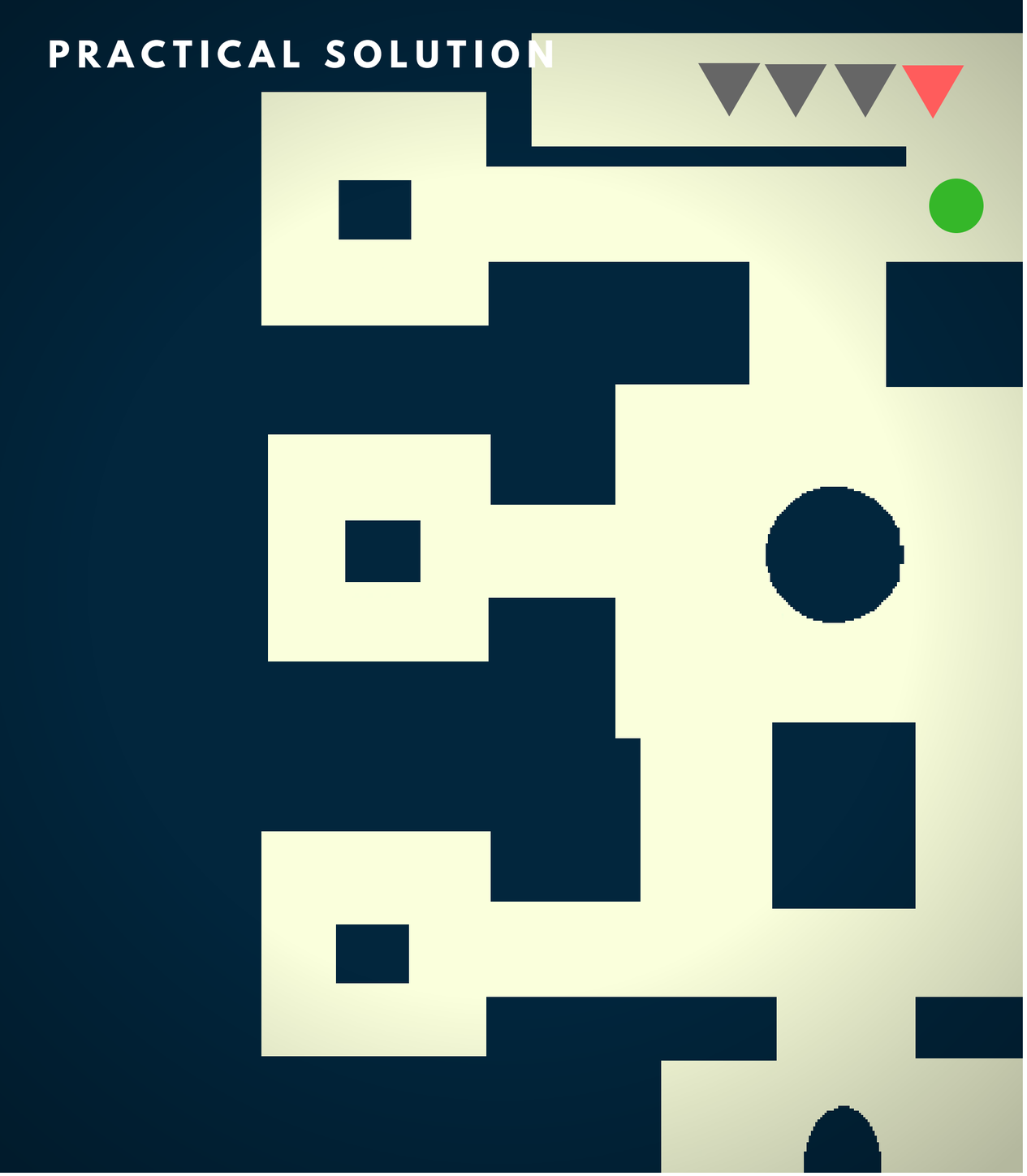
TWO MEASURES USEFUL TO COMPARE COORDINATION MECHANISMS

Interference

AVERAGE DISTANCE BETWEEN THE AGENTS

Availability

AVERAGE DISTANCE BETWEEN EACH AGENT AND ITS ASSIGNED FRONTIER



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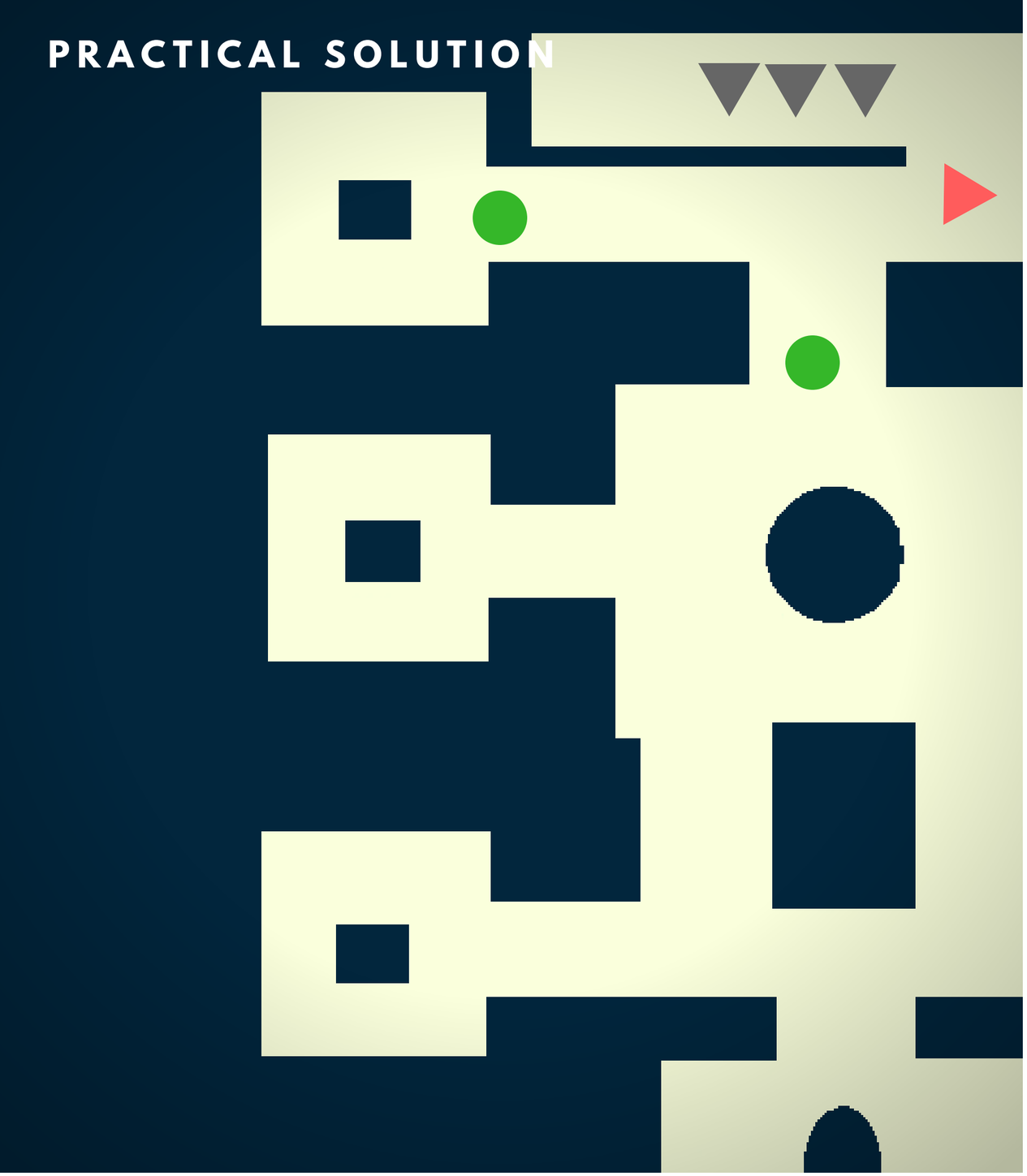
PROACTIVE RESERVE

1. ONE OF THE AGENTS IS INITIALIZED TO ACTIVE ROLE



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PROACTIVE RESERVE

1. ONE OF THE AGENTS IS INITIALIZED TO ACTIVE ROLE
2. AN ACTIVE AGENT CHOOSES THE CLOSEST AVAILABLE FRONTIER

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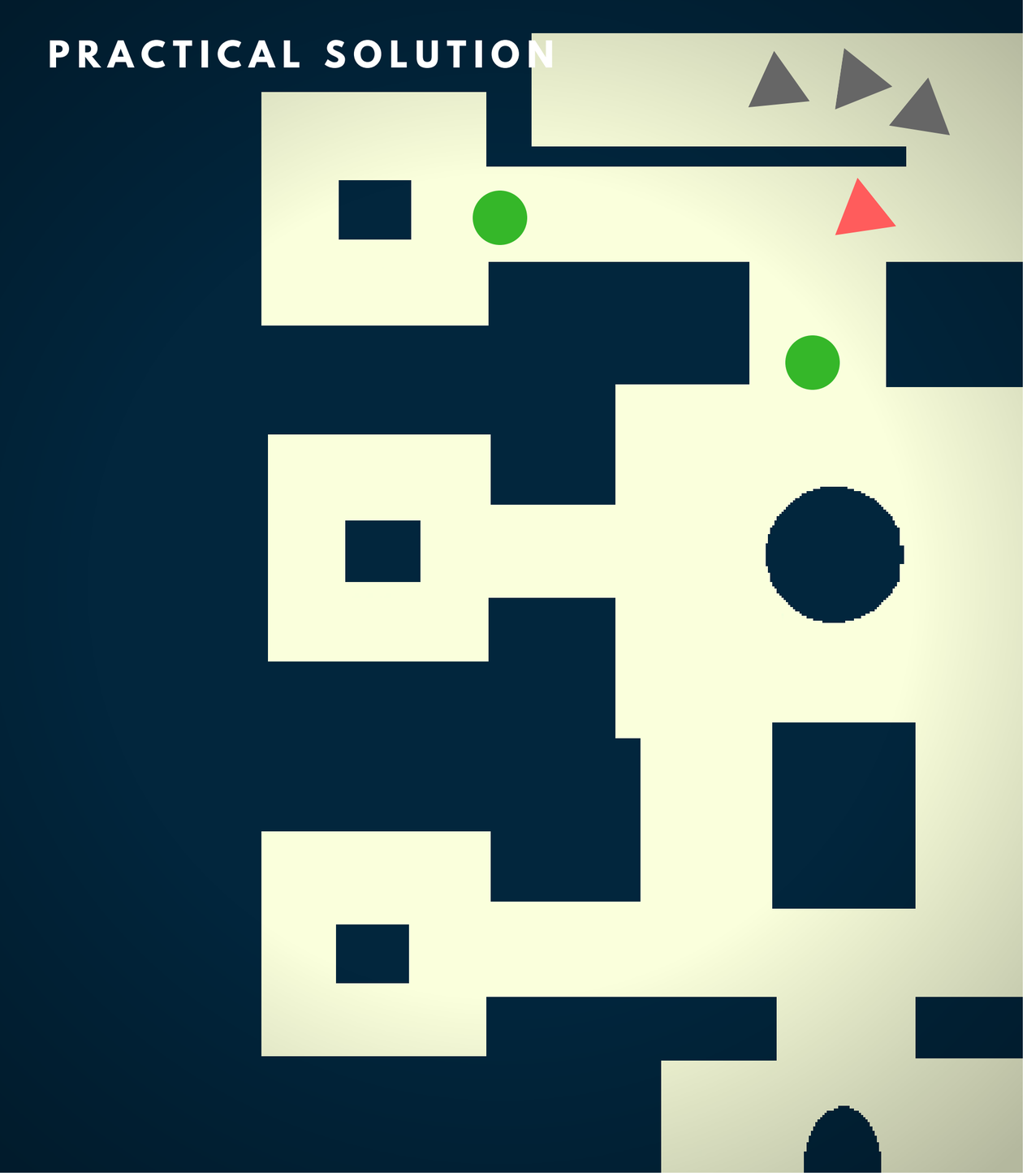

PROACTIVE RESERVE

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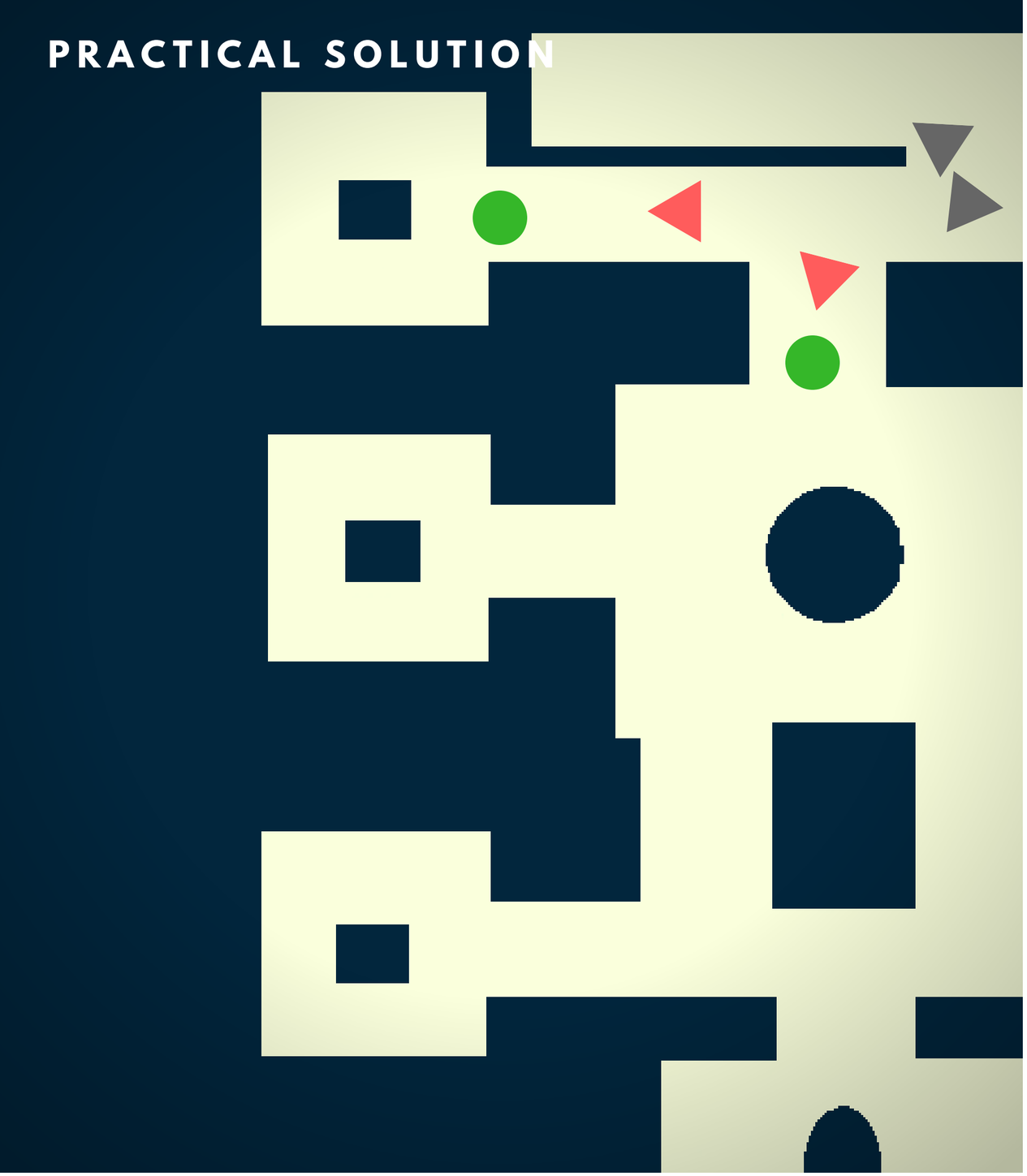
3. A RESERVE AGENT PROACTIVELY WAITS A CALL



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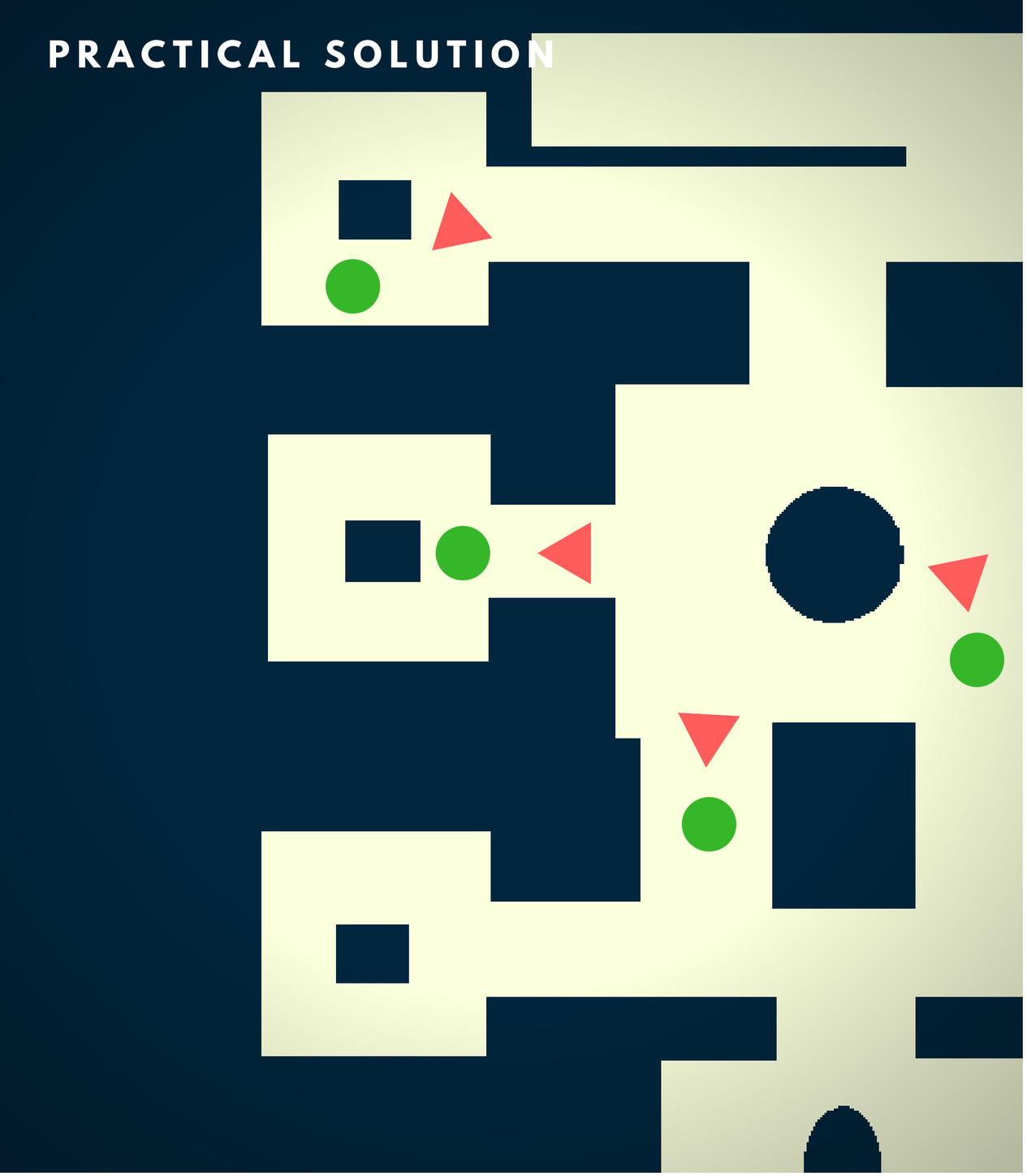
4. WHEN ACTIVE AGENTS DETECT A BRANCHING POINT, THEY CALL THEIR RESERVE TEAMMATES



PROACTIVE RESERVE

HIGH INTERFERENCE
HIGH AVAILABILITY

GOOD WHEN SPREADING AT THE BEGINNING

BAD IN LATER STEPS WHEN AGENTS ARE INDEPENDENT

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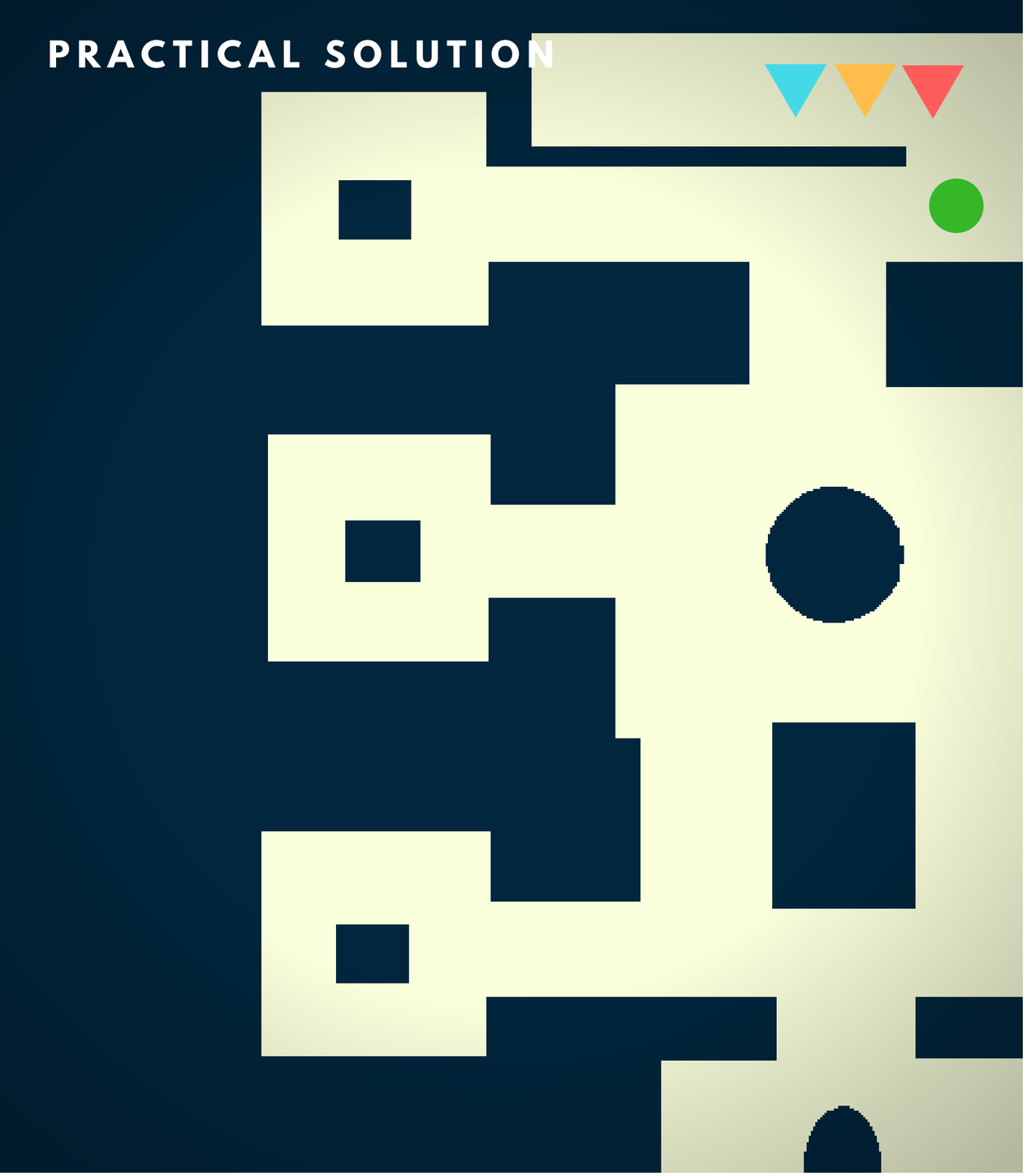

SIDE FOLLOWER

1. THREE ROLES: LEADER, LEFT FOLLOWER, RIGHT FOLLOWER

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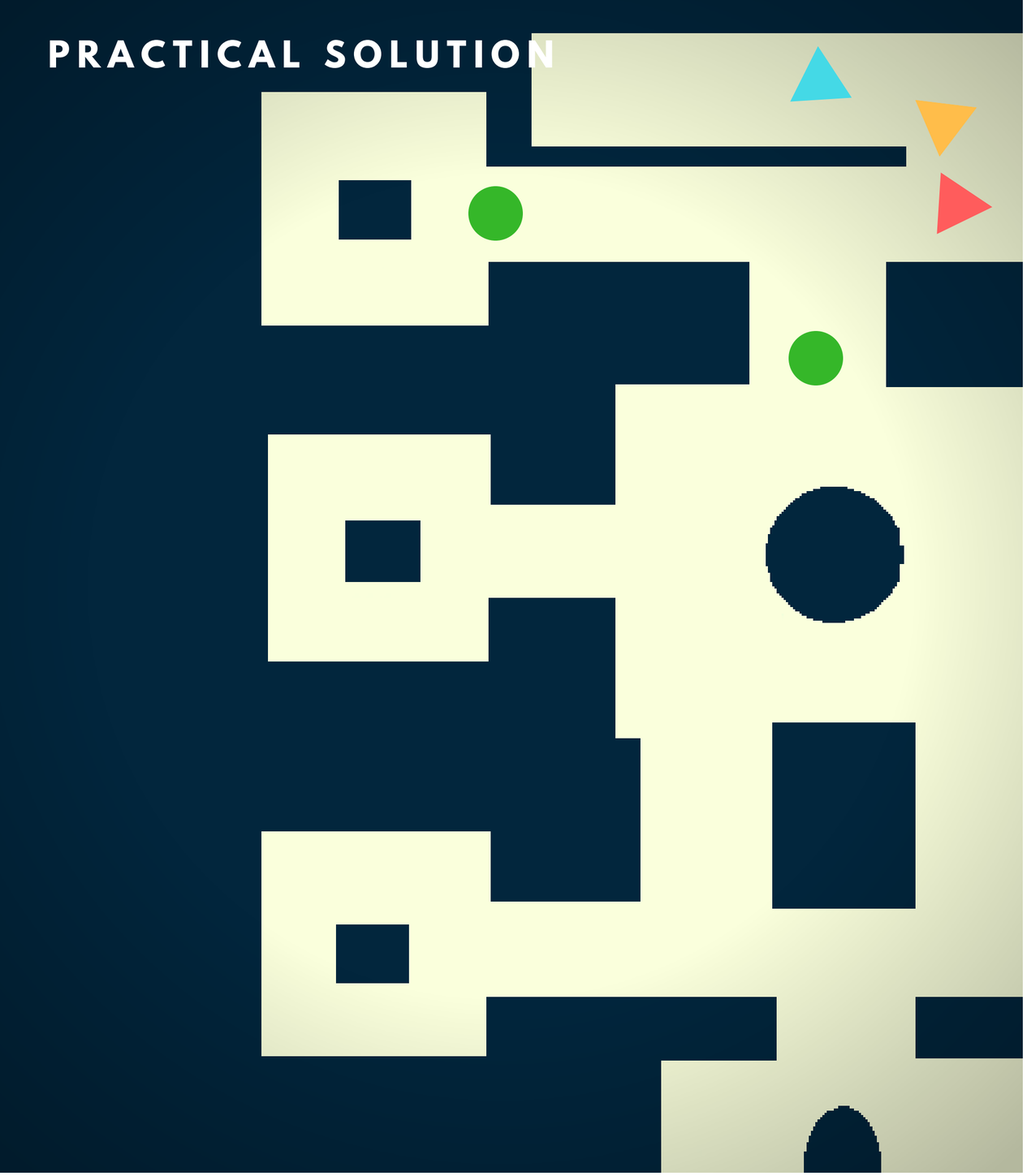

SIDE FOLLOWER

1. THREE ROLES: LEADER, LEFT FOLLOWER, RIGHT FOLLOWER

2. ALL THE AGENTS START AT THE SAME TIME

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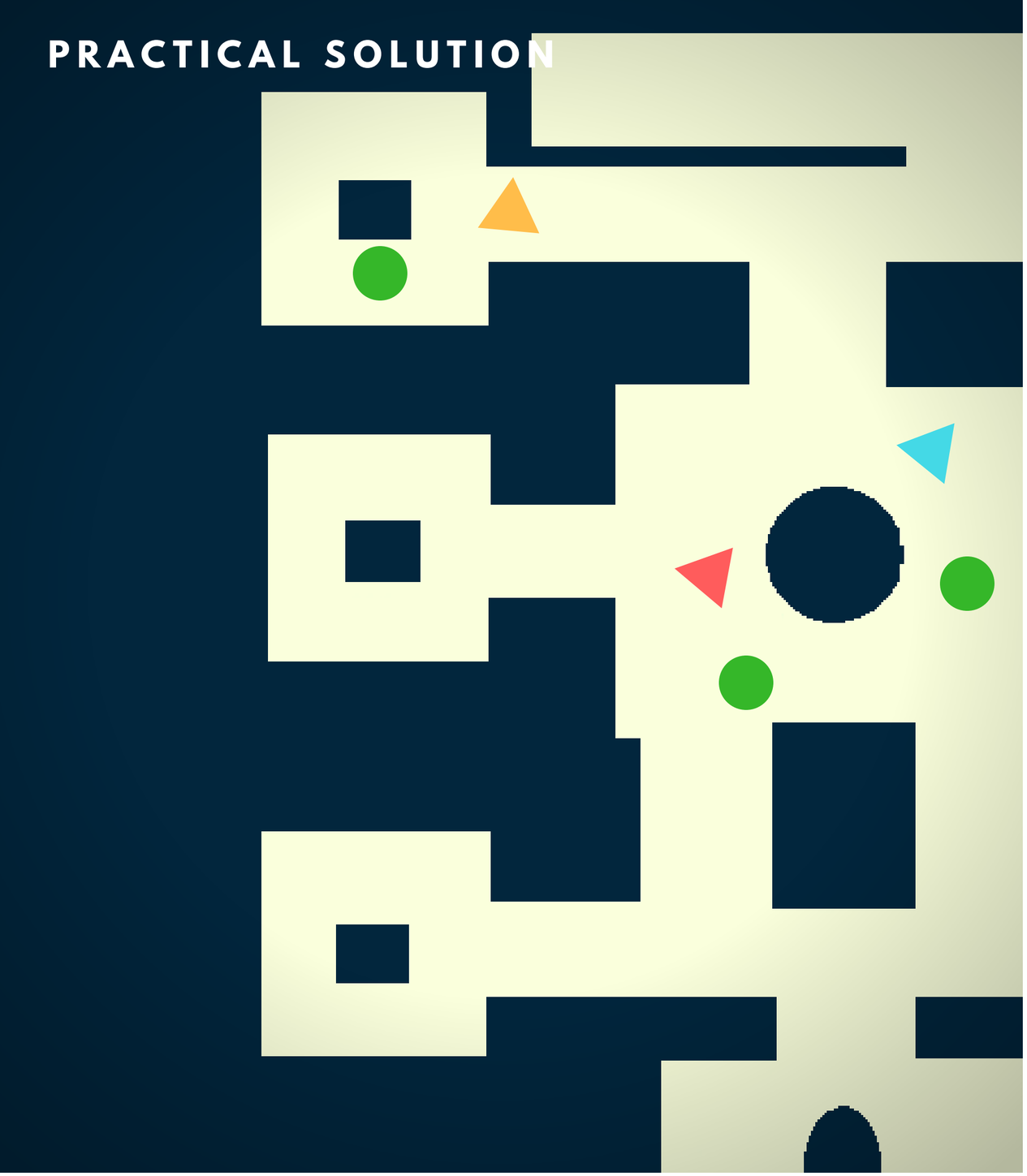

SIDE FOLLOWER

1. THREE ROLES: LEADER, LEFT FOLLOWER, RIGHT FOLLOWER

2. ALL THE AGENTS START AT THE SAME TIME

3. THE LEADER GOES STRAIGHT

4. THE RIGHT FOLLOWER GOES RIGHT

5. THE LEFT FOLLOWER GOES LEFT

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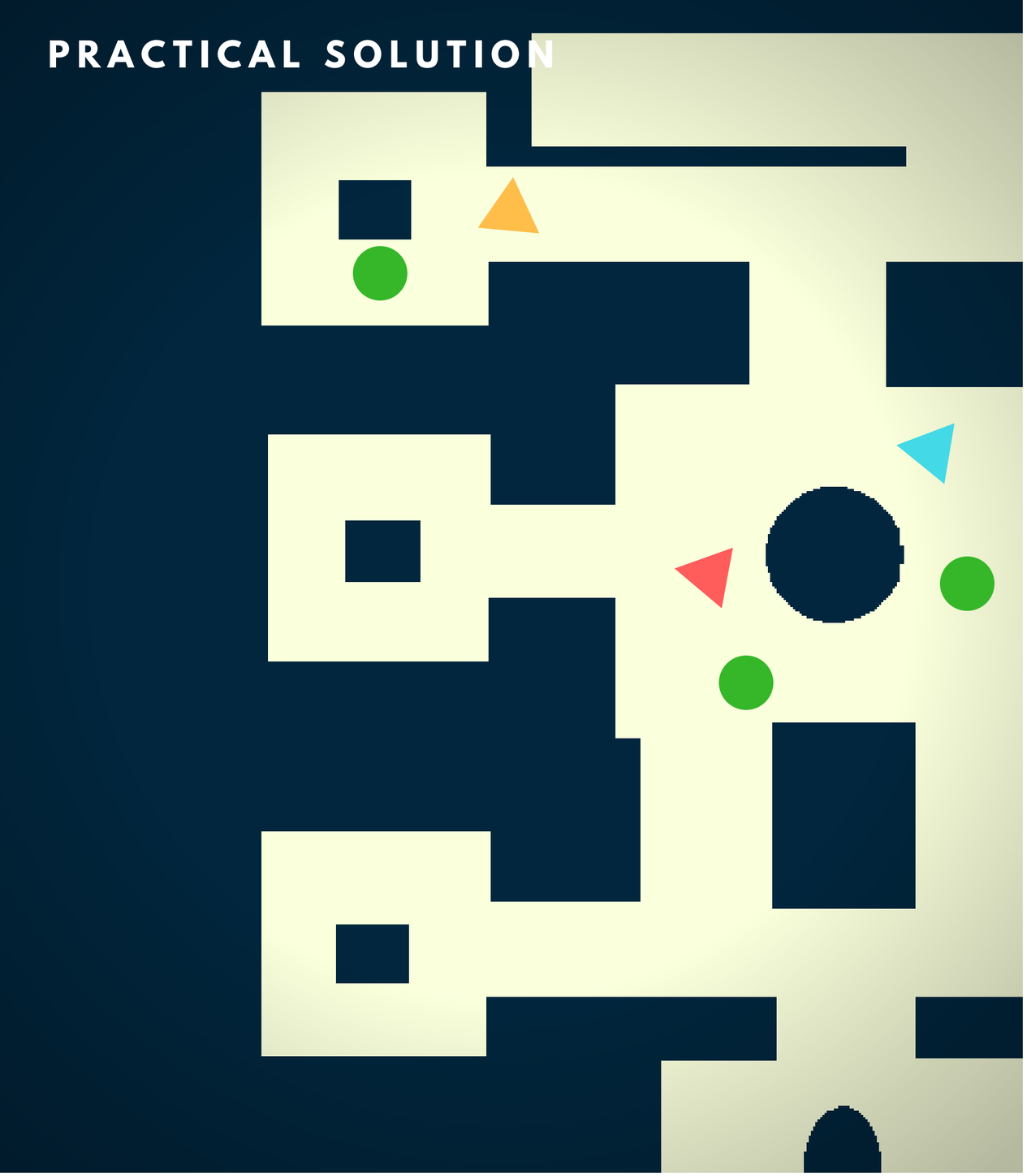
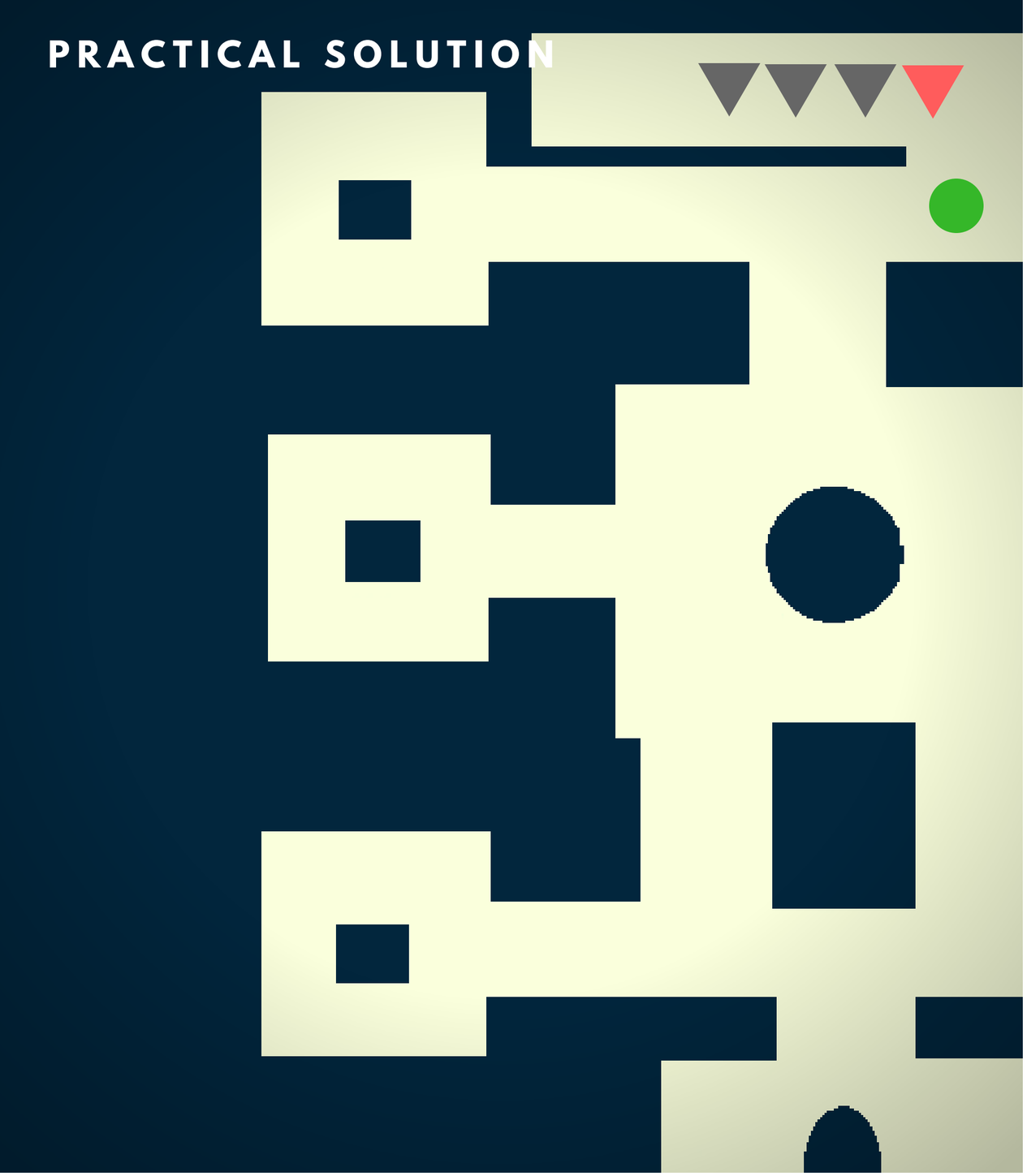


SIDE FOLLOWER

AVERAGE INTERFERENCE
AVERAGE AVAILABILITY

GOOD ON SPECIFIC ENVIRONMENTS

MAINTAINS COORDINATION UNTIL THE END



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DIRECT OPTIMIZATION

1. ONE OF THE AGENTS IS INITIALIZED TO ACTIVE ROLE

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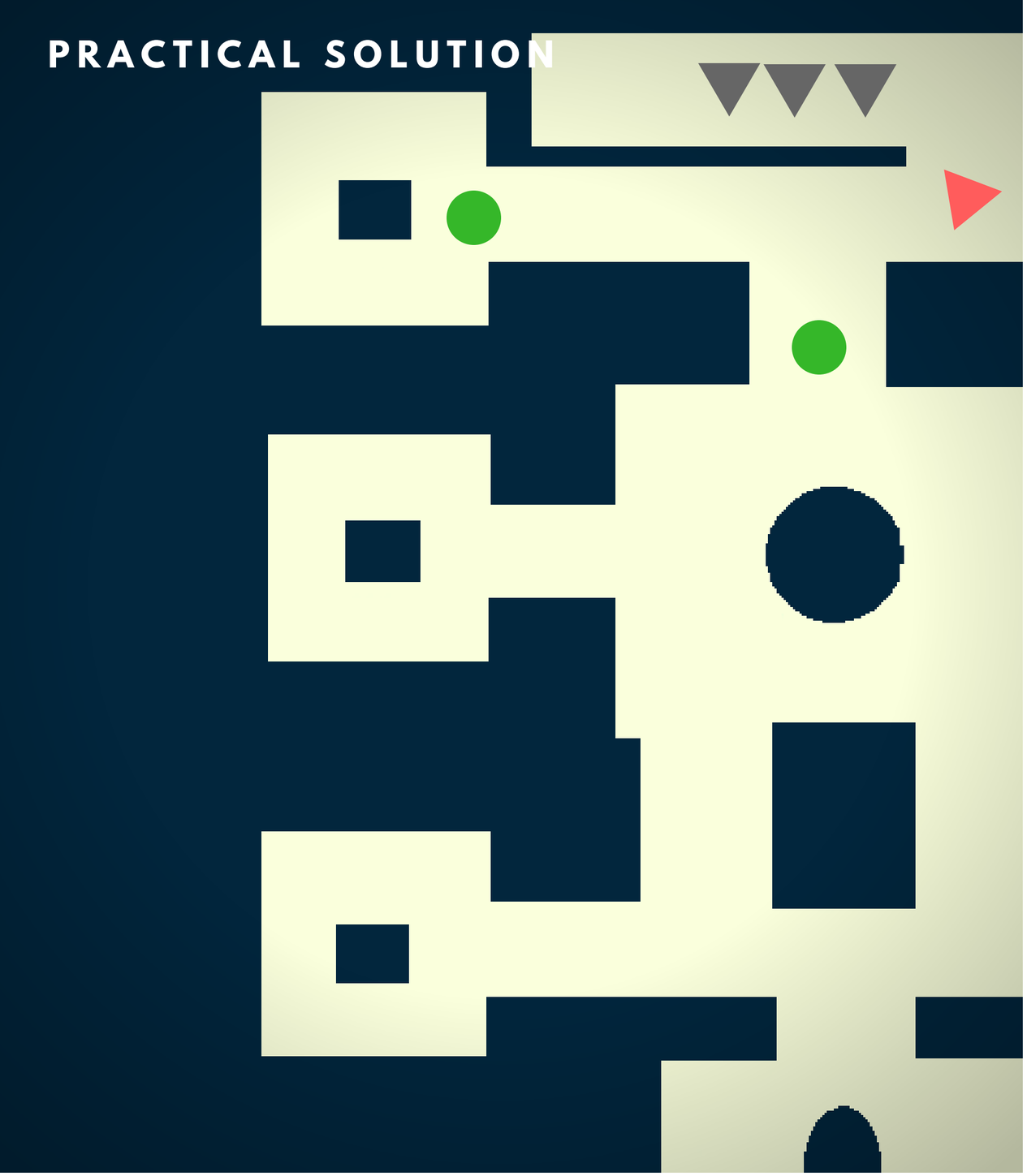

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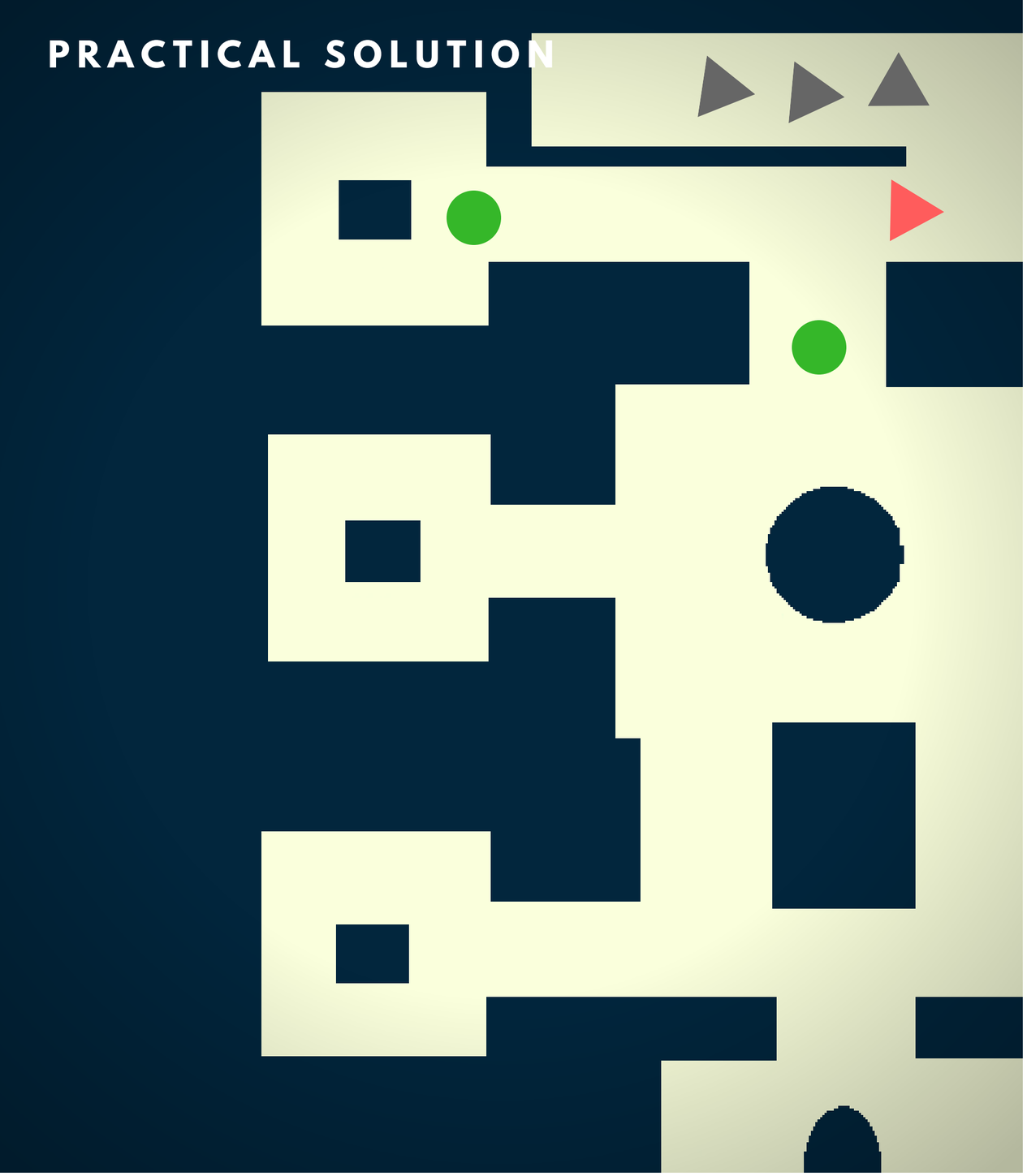

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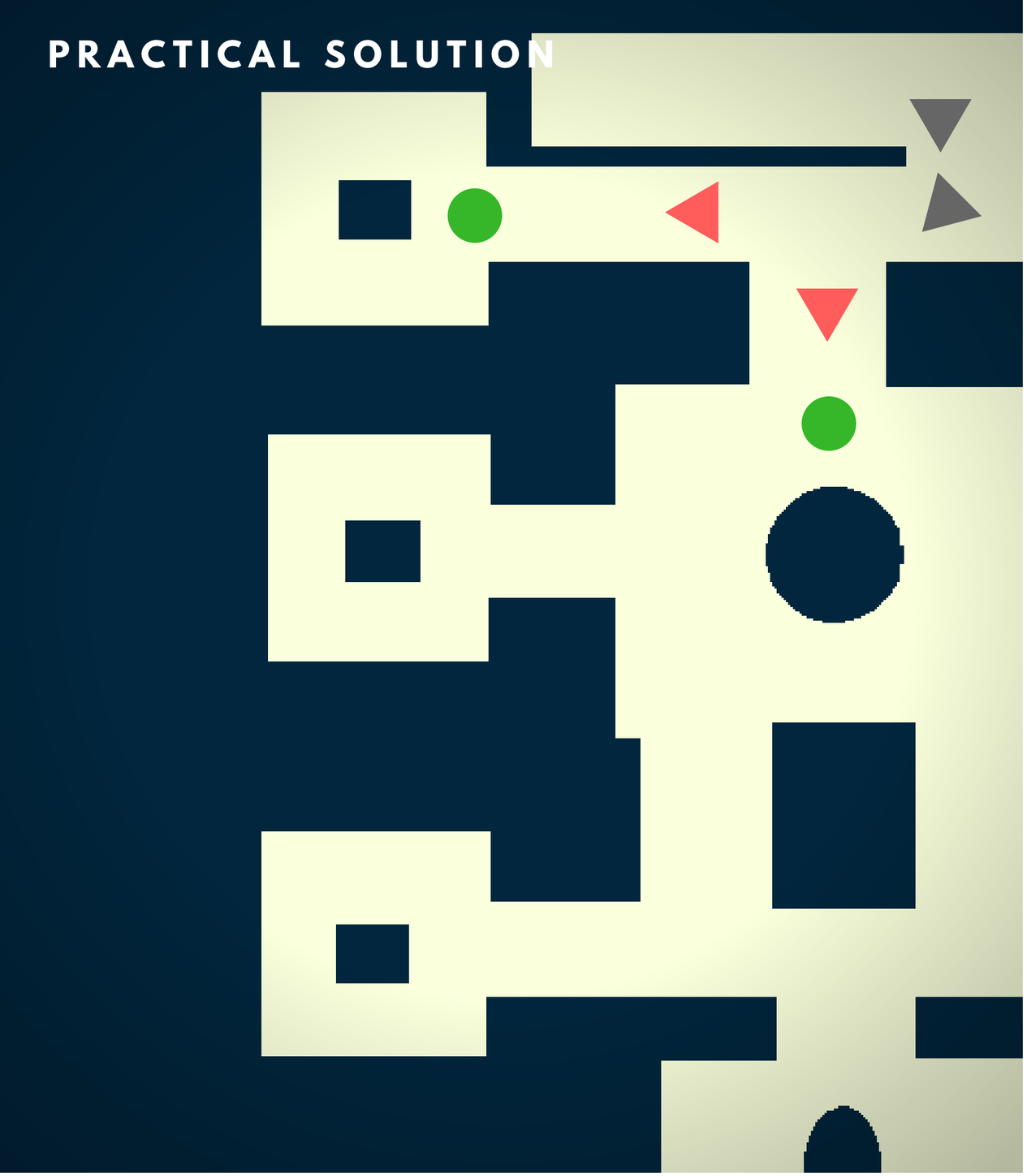

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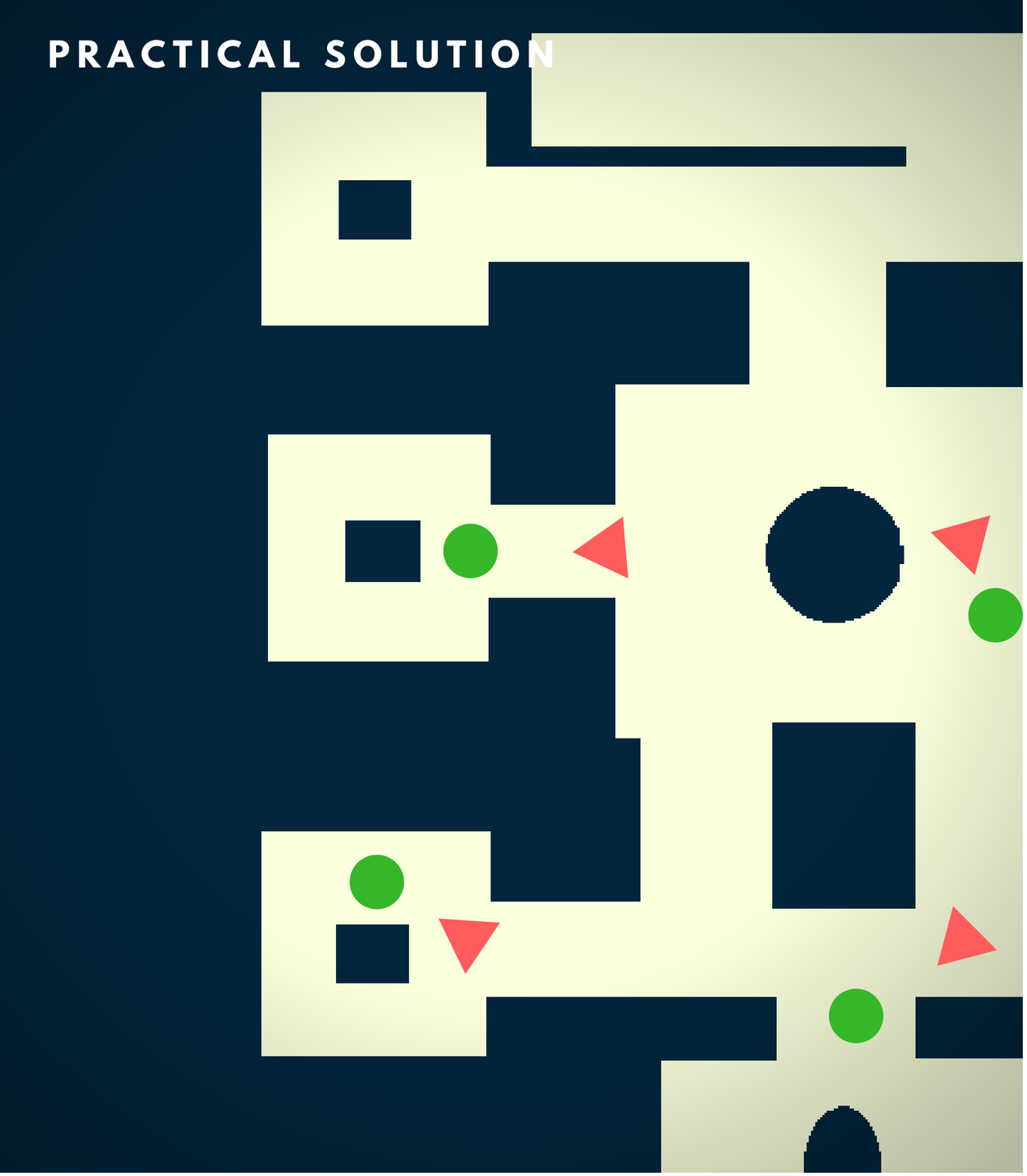

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4. WHEN ACTIVE AGENTS DETECT A BRANCHING POINT, THEY CALL THEIR RESERVE TEAMMATES
5. ACTIVE AGENTS SELECT A FRONTIER BASING ON THE DISTANCE AND ON THE NUMBER OF AGENTS ALLOCATED TO IT

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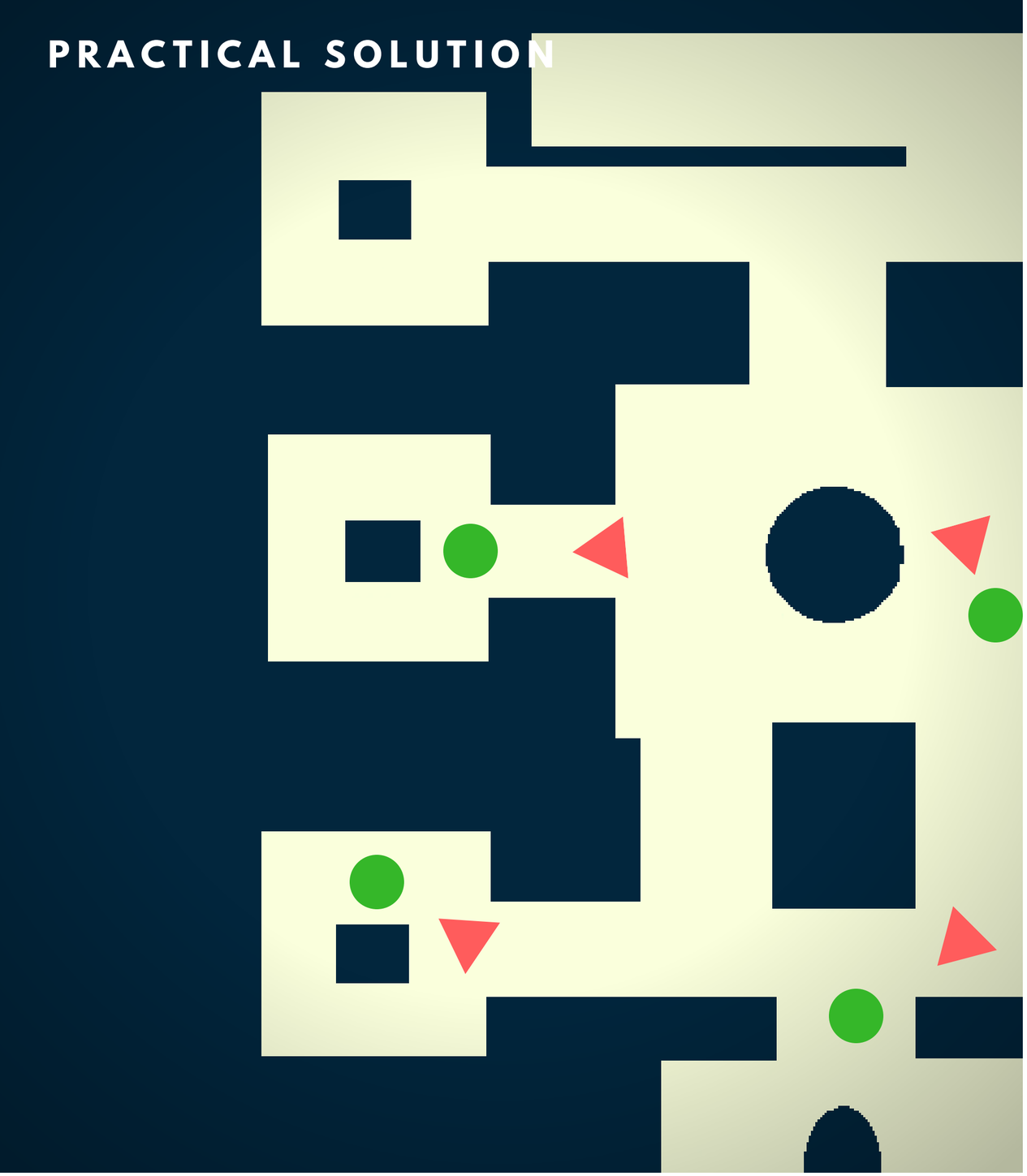


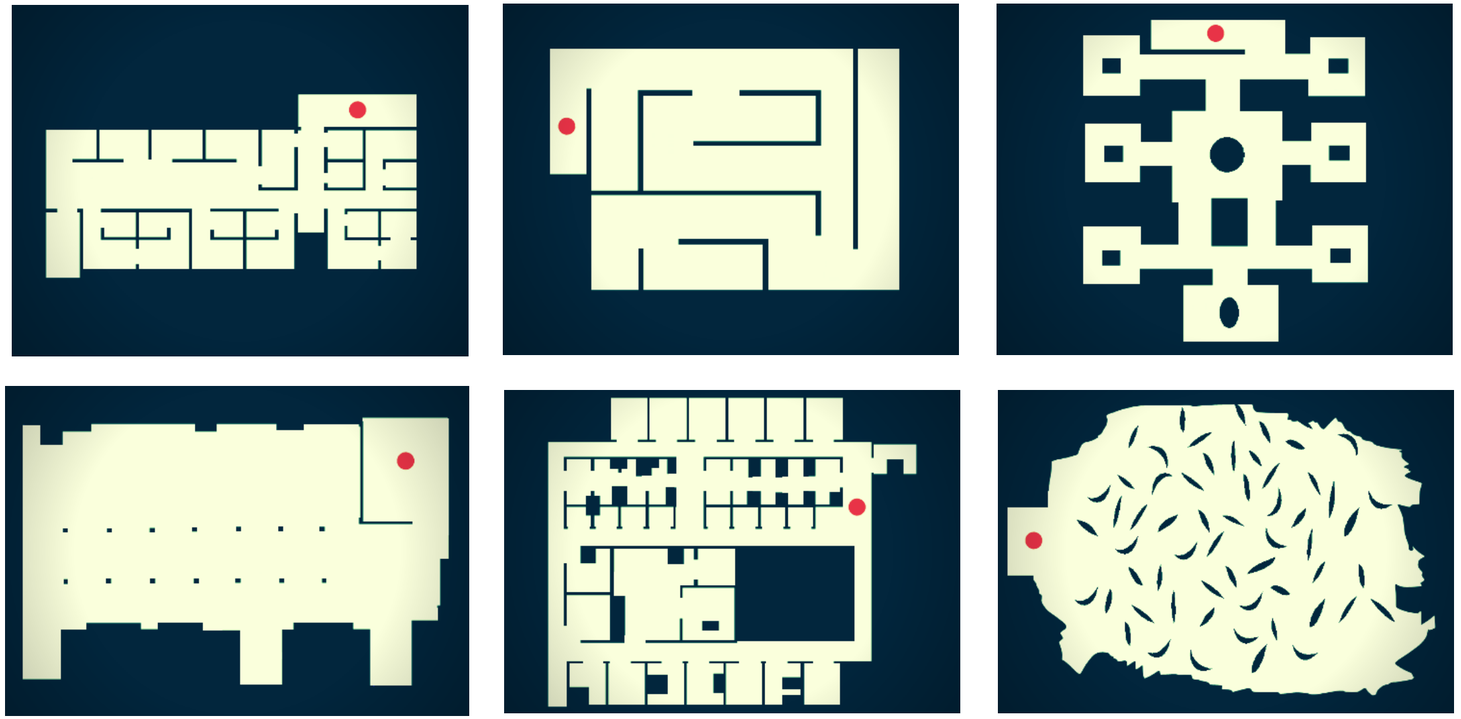
DIRECT OPTIMIZATION

HIGH INTERFERENCE
LOW AVAILABILITY

GOOD ON DIFFERENT ENVIRONMENTS

MAINTAINS COORDINATION UNTIL THE END

EXPERIMENTAL ENVIRONMENT



Simulation software

MRESIM

J. DE HOOG ET AL., 2009

Team size

FROM 2 TO 10 AGENTS

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EXPERIMENTAL MEASURES

EXPLORATION TIME

The goal of a mechanism is to minimize the exploration time

INTERFERENCE

The goal of a mechanism is to maximize the interfernce measure

AVAILABILITY

The goal of a mechanism is to minimize the availability measure

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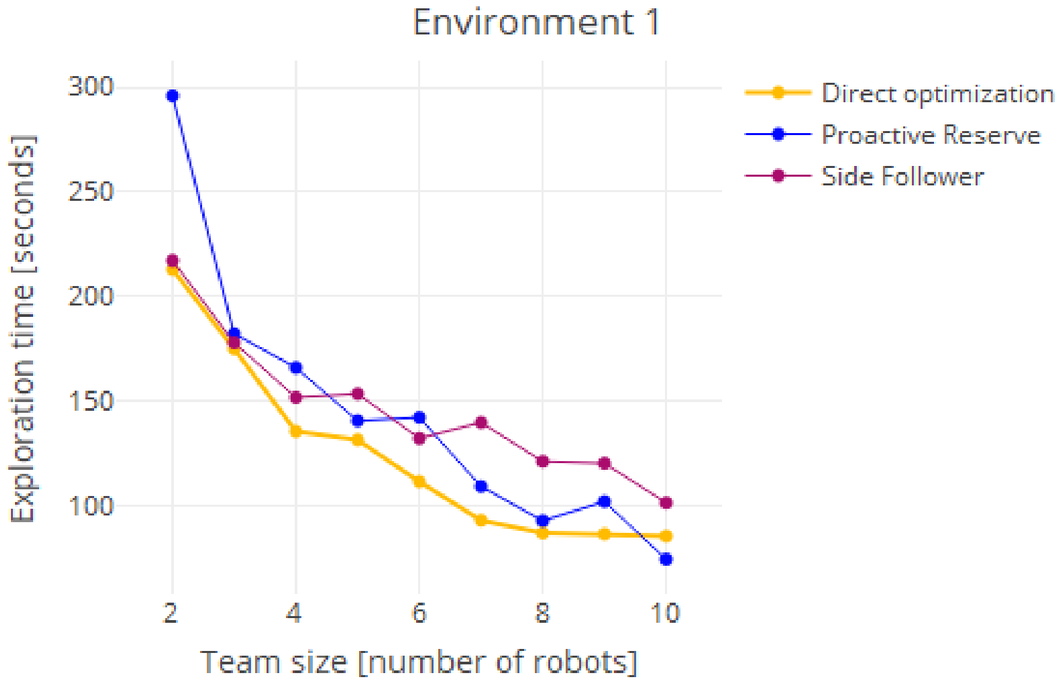
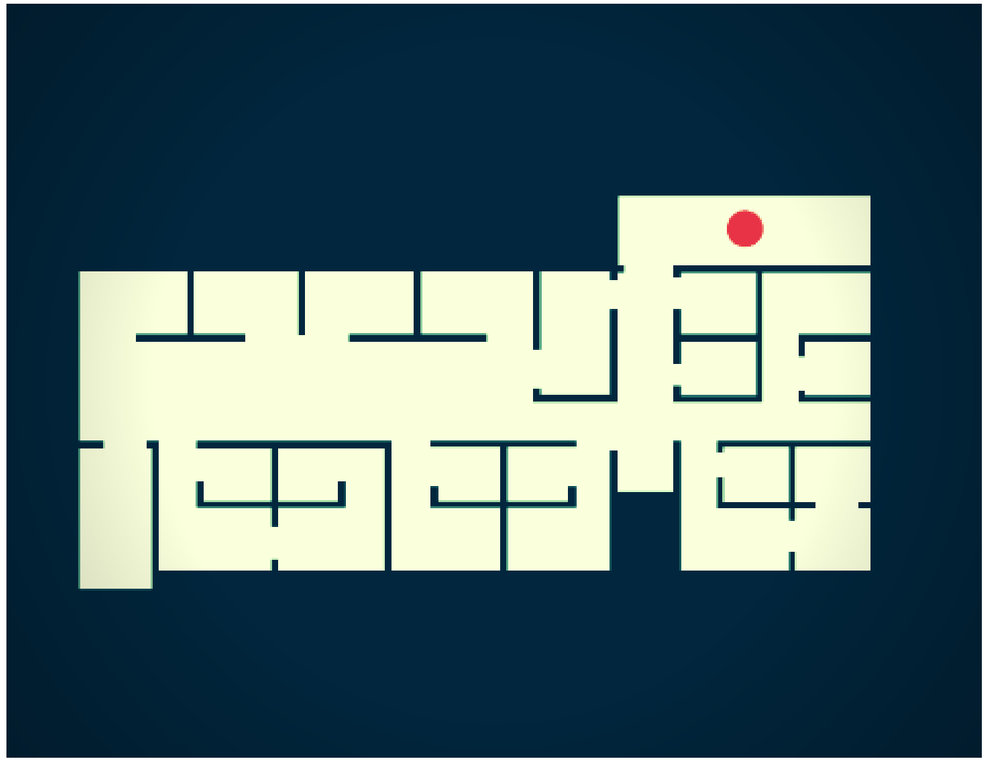
EXPERIMENTAL RESULTS





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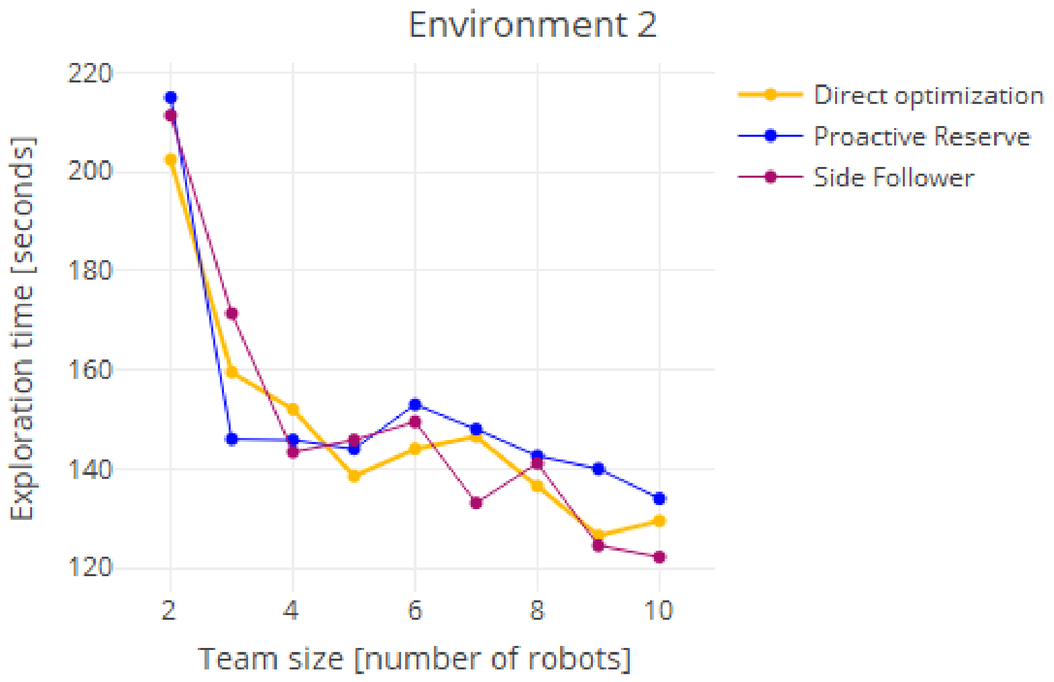

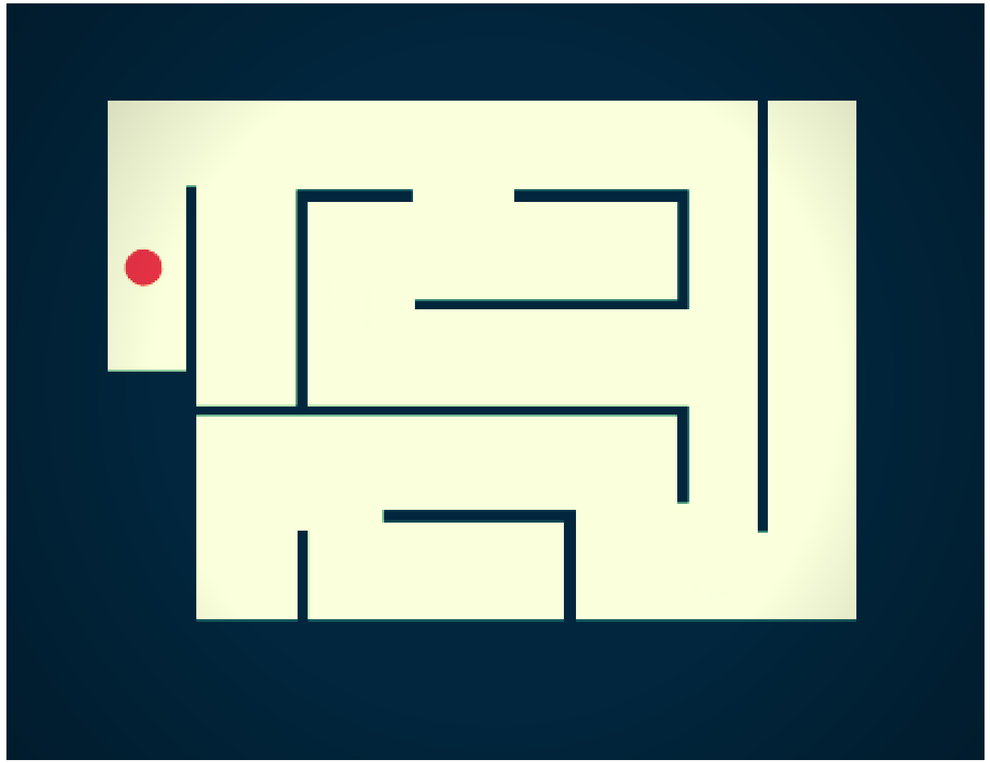

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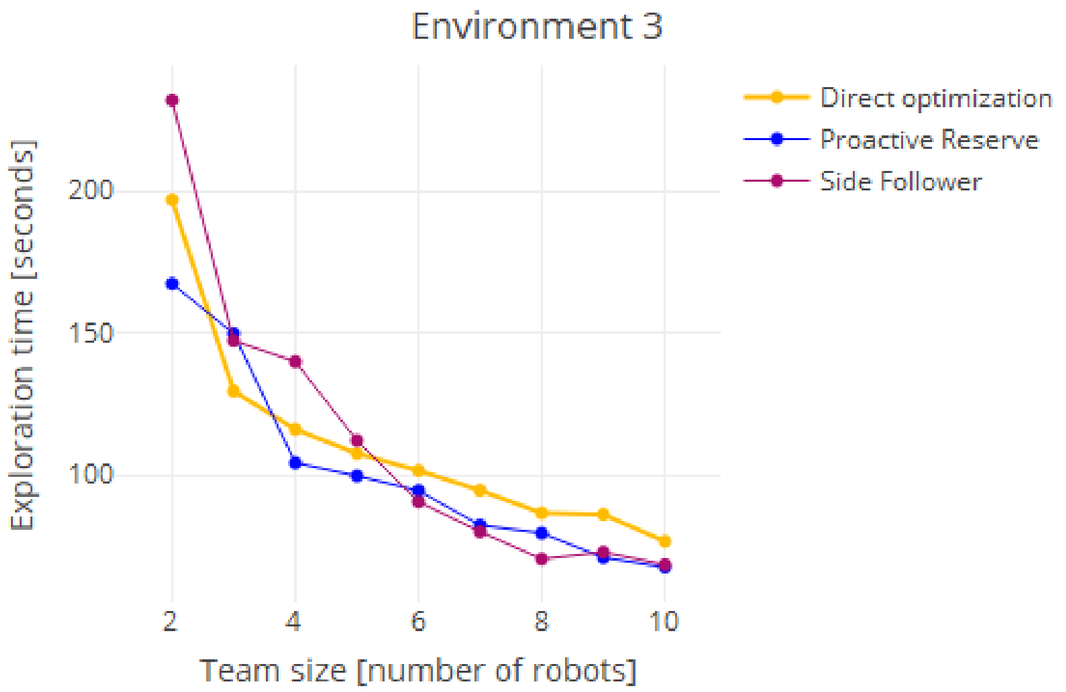

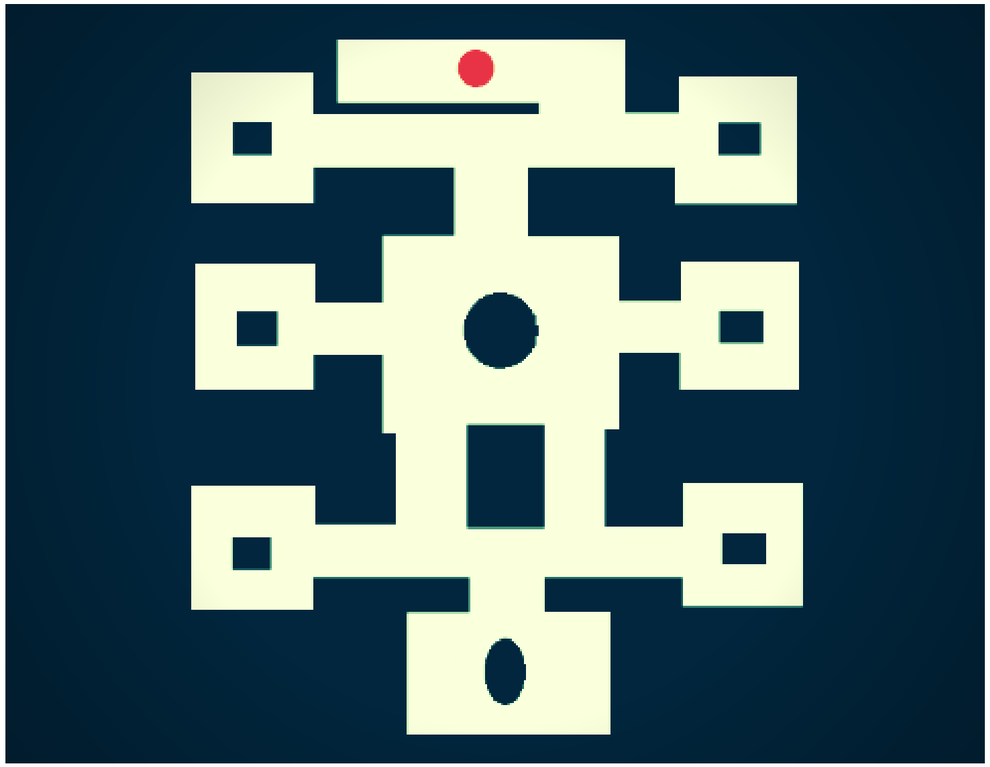

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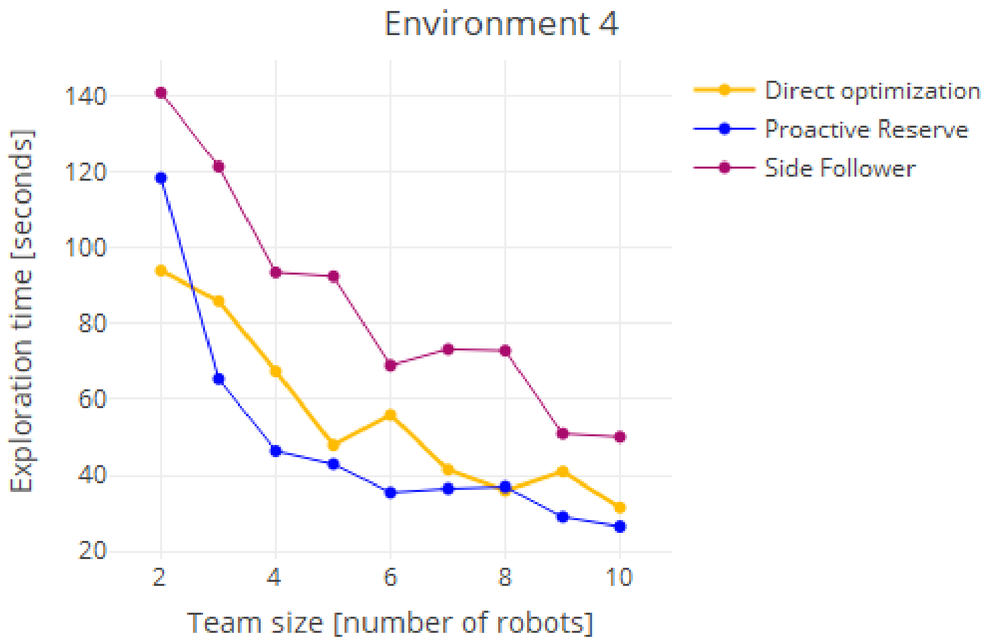

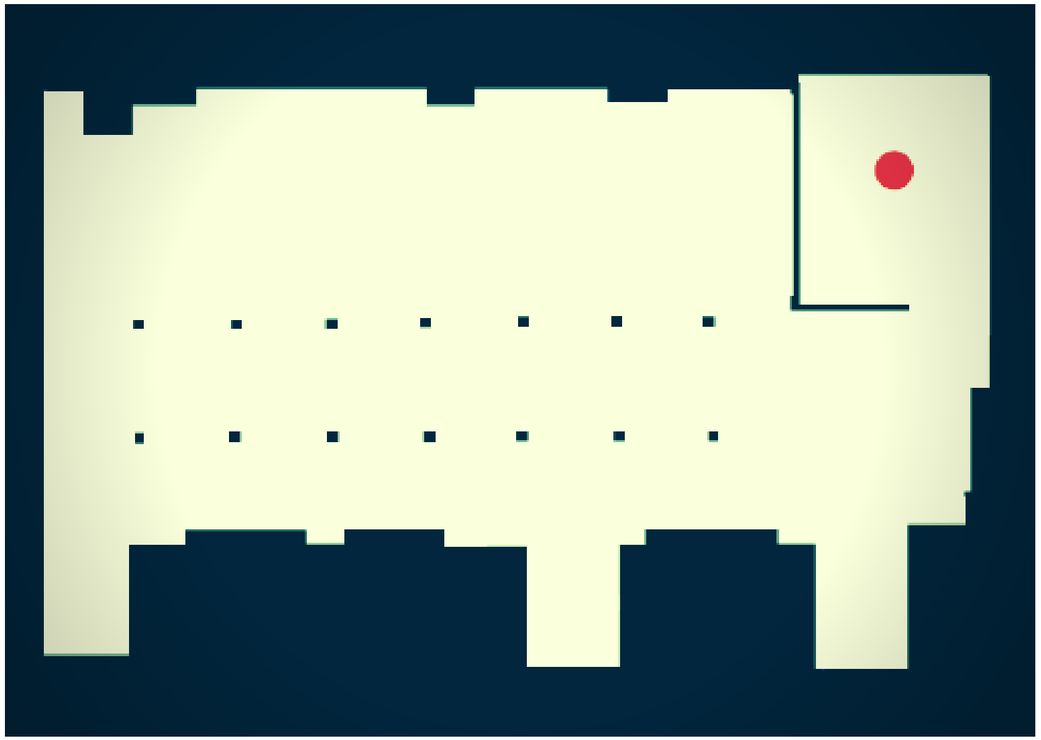

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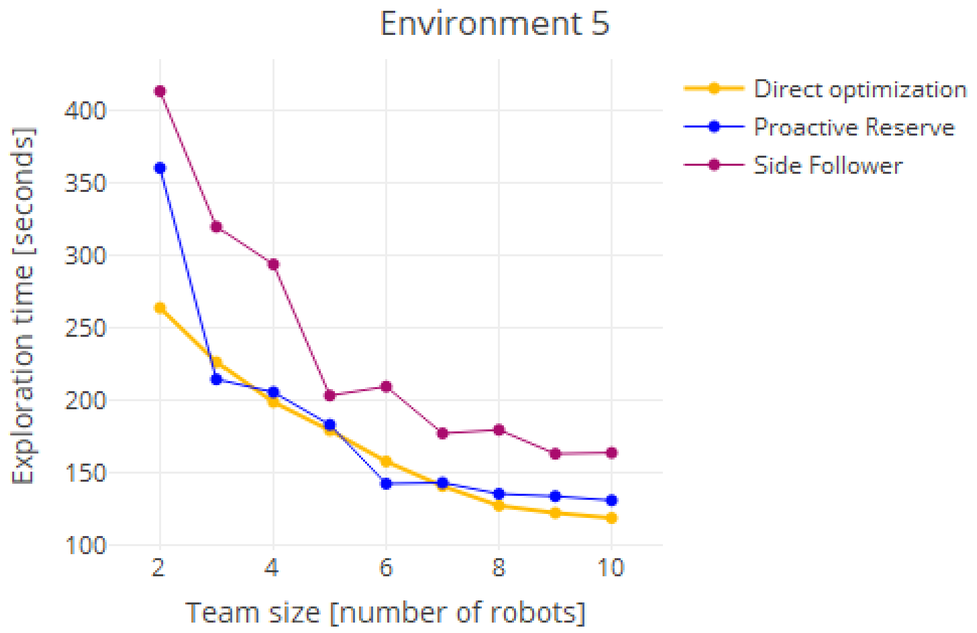

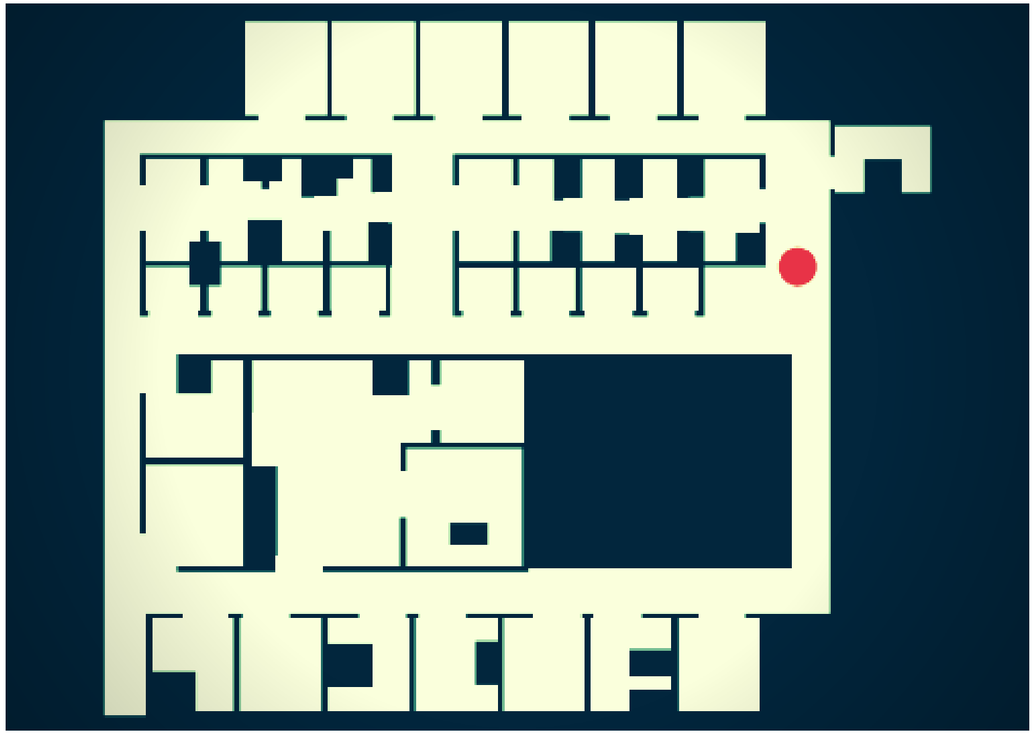

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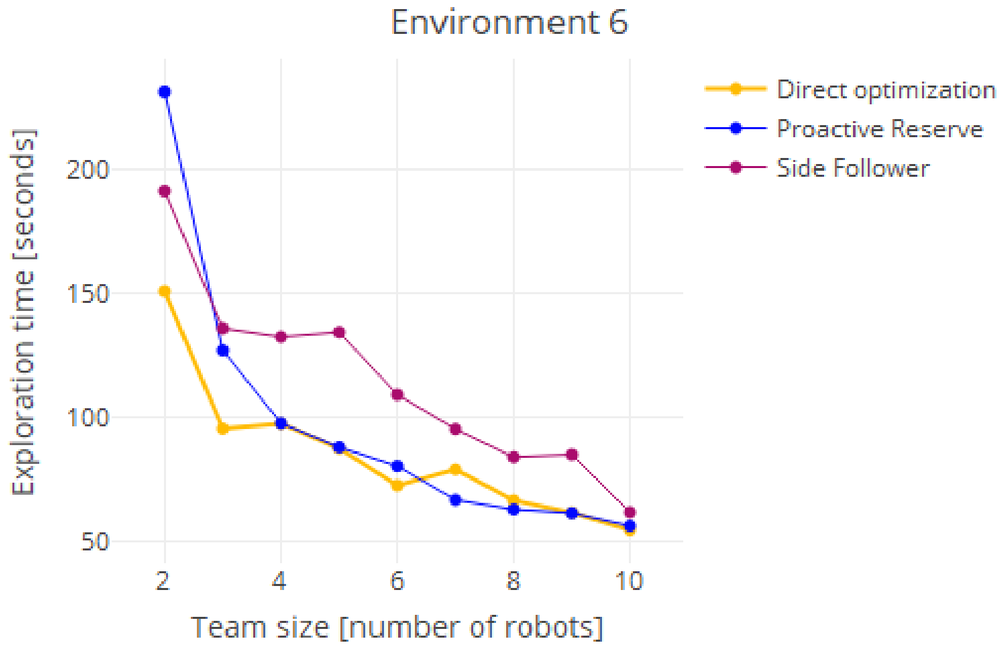

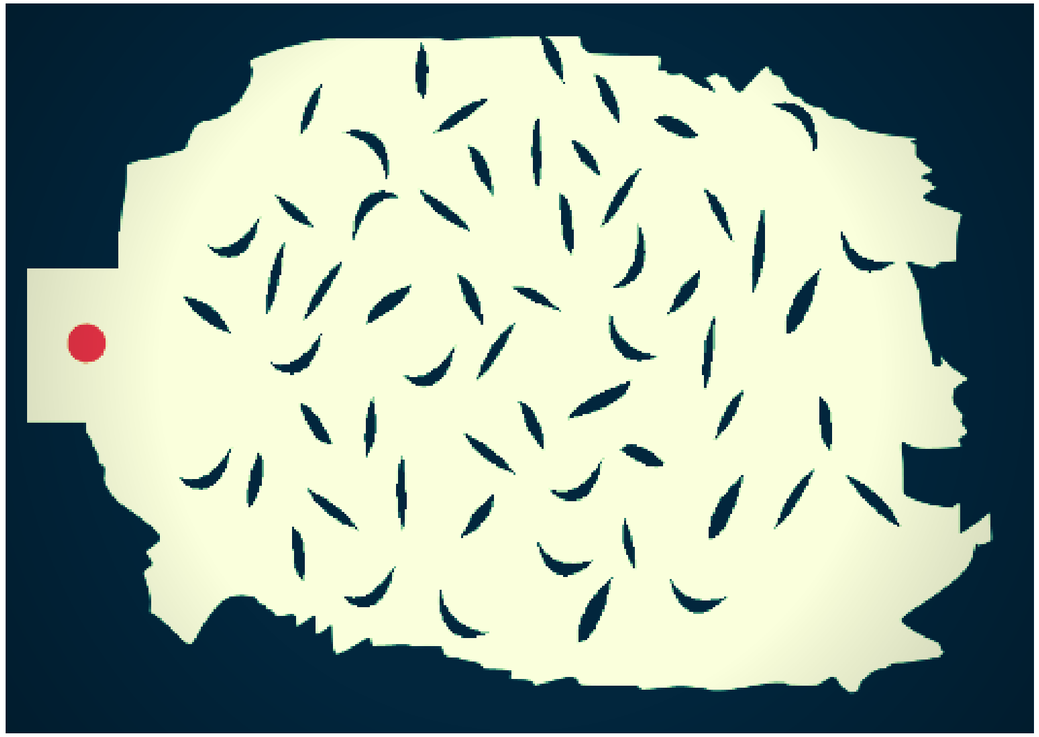

CONCLUSIONS

ONLINE MECHANISMS

Online mechanisms seem to perform better on fragmented and cluttered environments

OFFLINE MECHANISMS

CONCLUSIONS

ONLINE MECHANISMS

Online mechanisms seem to perform better on fragmented and cluttered environments

OFFLINE MECHANISMS

Offline mechanisms seem to perform better on open and highly parallelizable environments

CONCLUSIONS

FRAMEWORK EVALUATION

Interference and availability help in the design and a priori evaluation of the mechanisms

BETTER FOR ONLINE MECHANISMS

TO BE IMPROVED FOR OFFLINE DESCRIPTION

CONCLUSIONS

FRAMEWORK EVALUATION

BETTER FOR ONLINE MECHANISMS

The proposed framework is closer to online approach in the utility computation formalism

TO BE IMPROVED FOR OFFLINE DESCRIPTION

CONCLUSIONS

FRAMEWORK EVALUATION

BETTER FOR ONLINE MECHANISMS

The utility computation formalism is more familiar to online mechanisms

TO BE IMPROVED FOR OFFLINE DESCRIPTION

FUTURE WORK

EXPLORE THE RELATIVE CONTRIBUTIONS OF INTERFERENCE AND AVAILABILITY

ENRICH THE MODEL TO DESCRIBE CLEARLY THE COORDINATION MECHANISMS, IN PARTICULAR OFFLINE

DEVELOP AND TEST MORE MECHANISMS BASING ON THE FRAMEWORK PROPOSED