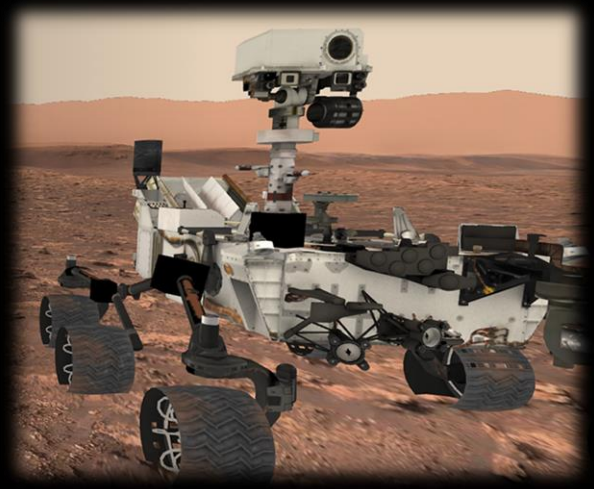
PROVING LUNAR AUTONOMOUS MICRO-ROVING MISSIONS WILL SUCCEED

Varsha Kumar

AUTONOMOUS NAVIGATION IS THE FUTURE OF PLANETARY ROVING.

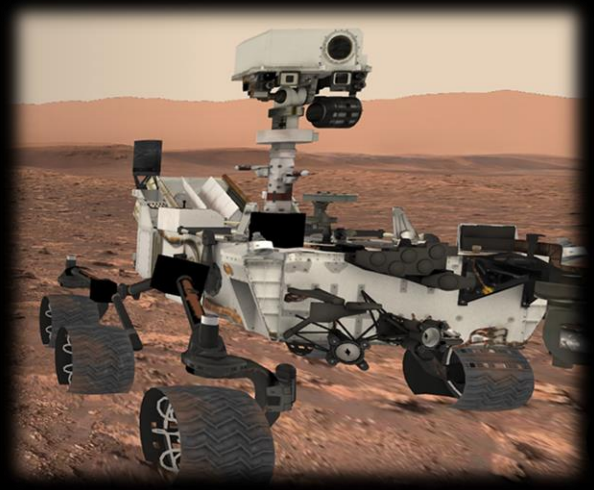
Mars Rovers: Multi-Year, $$$,
Step-Stop-Drive (slow)



Autonomous Rovers: Week-Long, $,
Continuous Motion (fast)

LUNAR MICRO-ROVER MISSIONS ARE OF SHORT DURATION.

SMALL ROVER => NO ISOTOPE HEATING



LUNAR DAY ONLY LASTS 14 EARTH DAYS

CAN AUTONOMOUS ROVER MISSIONS SUCCEED?

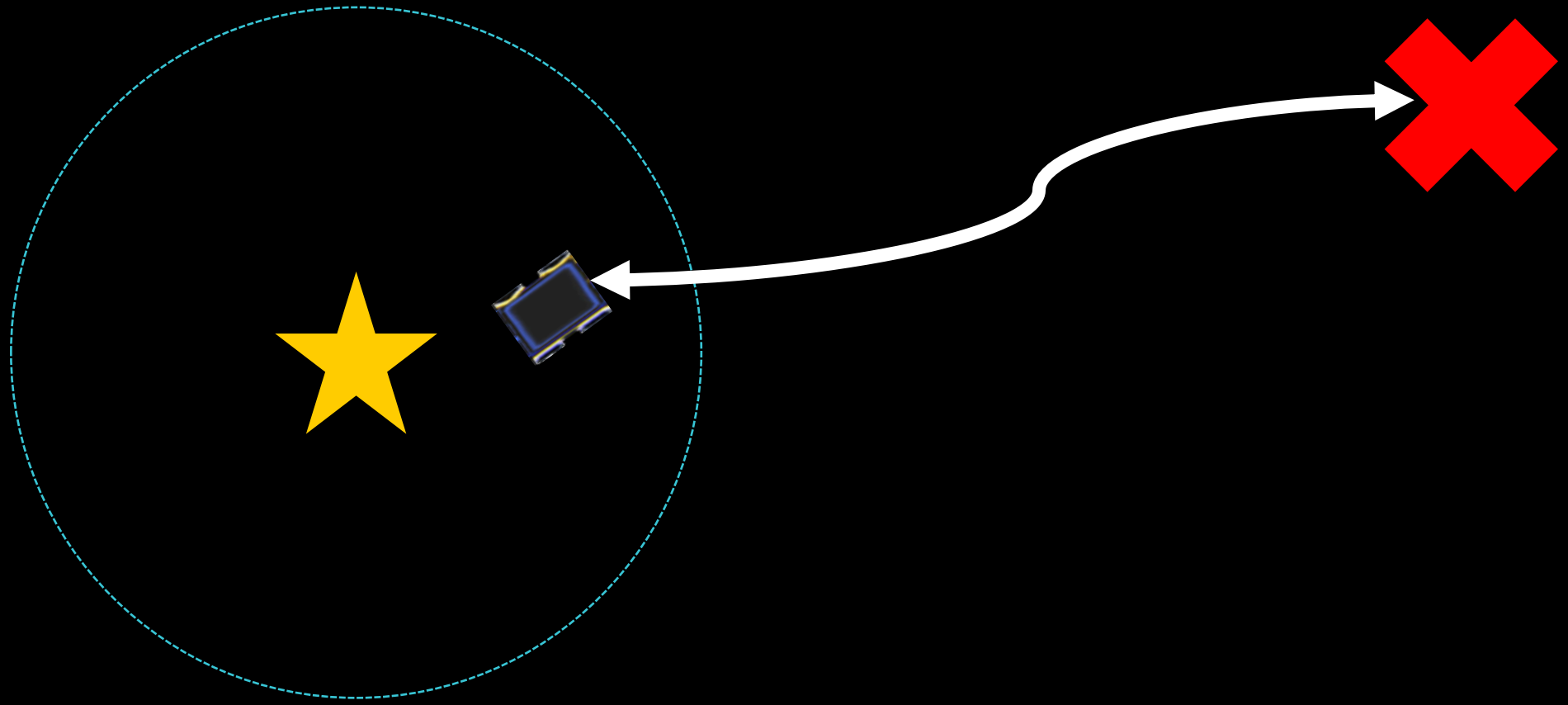
CAN AUTONOMOUS ROVER MISSIONS SUCCEED?

KeymeraX *for a Formal Proof*

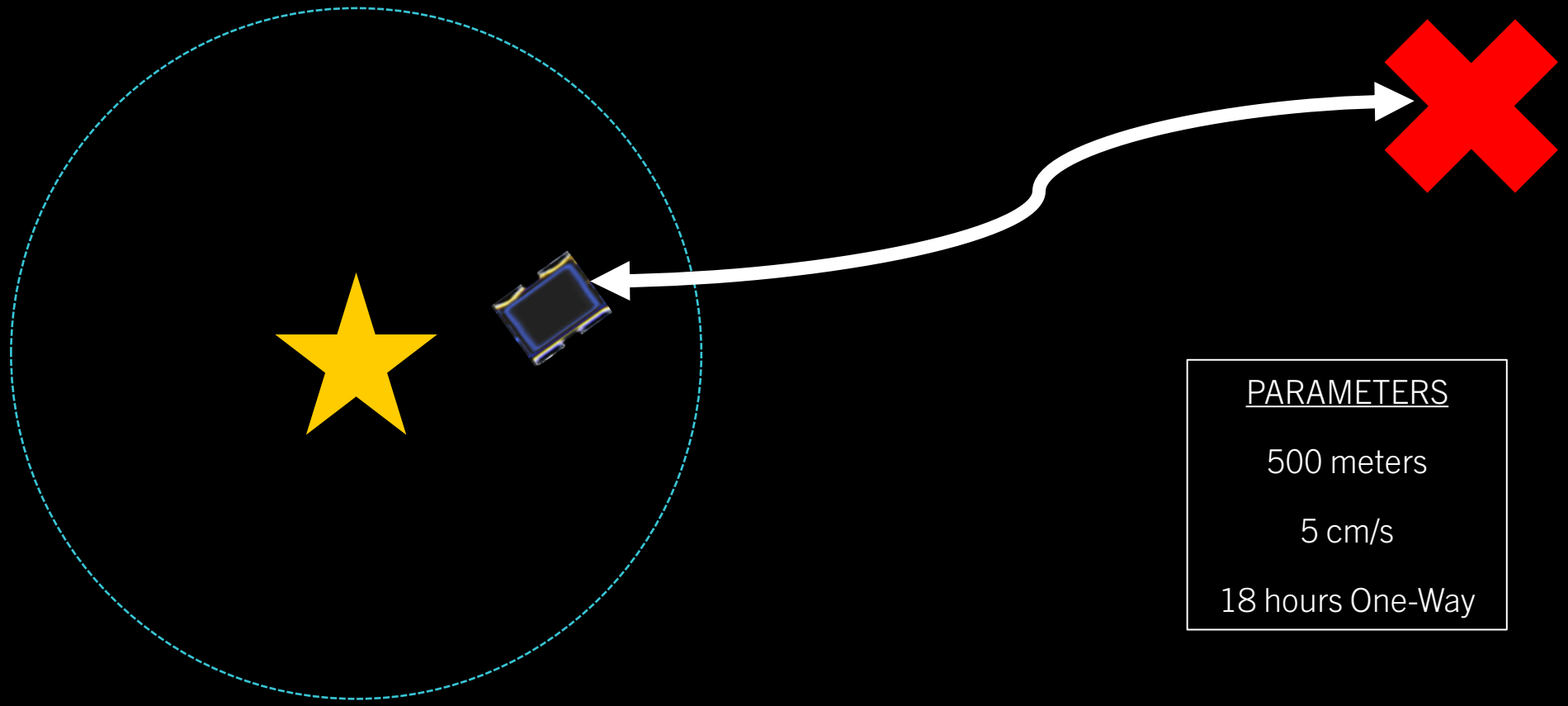
OUTLINE

- Background: Can Autonomous Rover Missions Succeed?
- Problem: Proving A Successful Autonomous Micro-Rover Mission
- Model Methodology
- Proof: Choosing the Correct Time Bound
- Extensions: Additional Obstacles, Arcs Needed, and Mission Time RE: Rock Distribution
- Questions

SUCCESS IS EXPLORATION WITHIN TIME



SUCCESS IS EXPLORATION WITHIN TIME



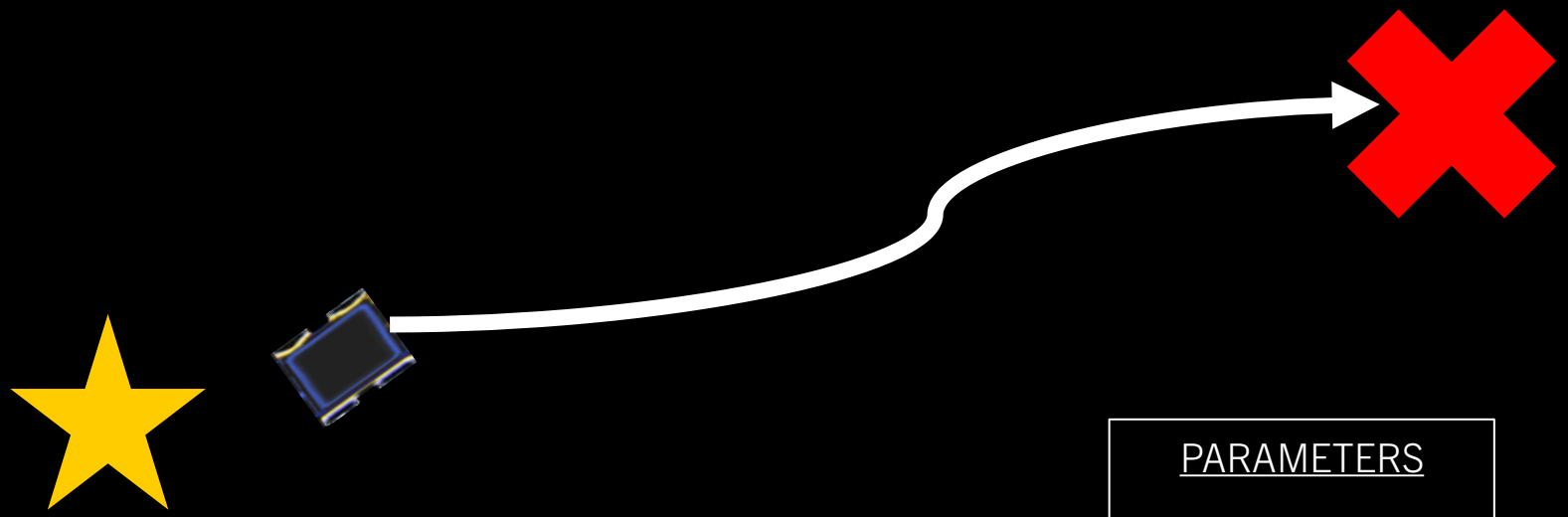
PARAMETERS

500 meters

5 cm/s

18 hours One-Way

STREAMLINE THE PROBLEM: ONE DIRECTION



PARAMETERS

500 meters

5 cm/s

18 hours One-Way

STREAMLINE THE PROBLEM: MOTION ON X-AXIS

PARAMETERS

500 meters

5 cm/s

18 hours One-Way

STREAMLINE THE PROBLEM:
MOTION ON X-AXIS + OBSTACLES

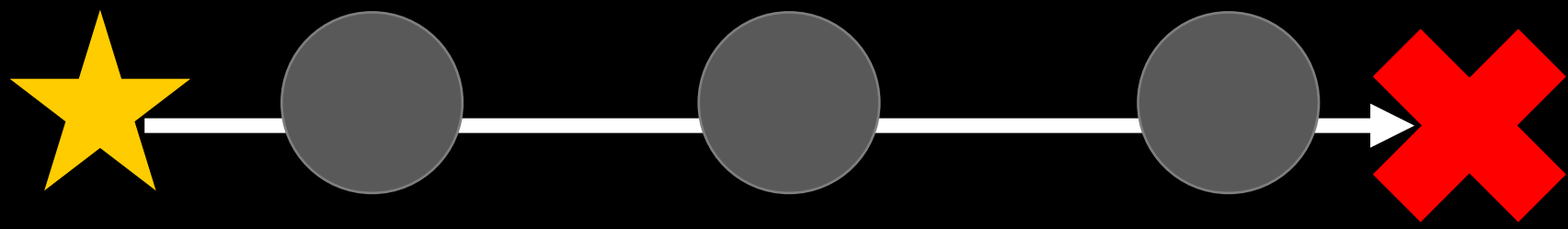
PARAMETERS

500 meters

5 cm/s

18 hours One-Way

STREAMLINE THE PROBLEM: CIRCULAR OBSTACLES



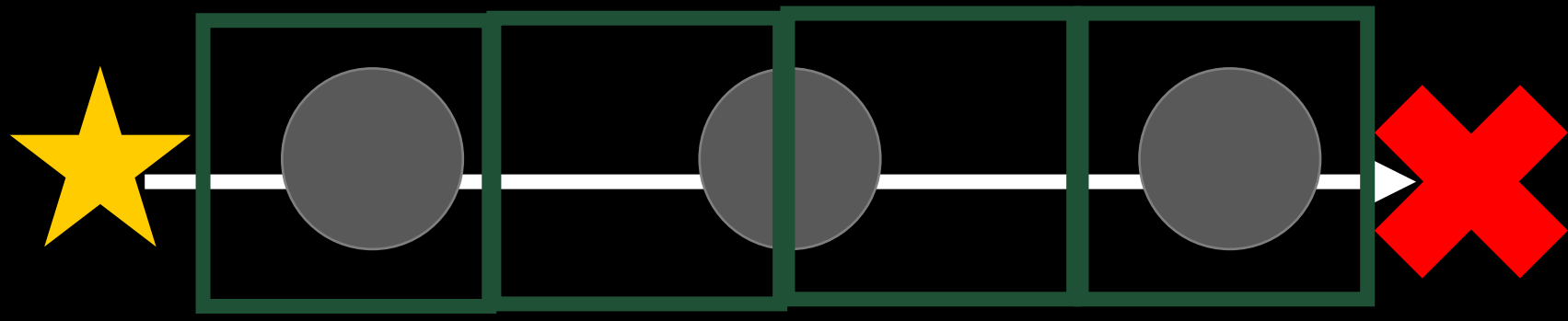
PARAMETERS

500 meters

5 cm/s

18 hours One-Way

STREAMLINE THE PROBLEM: WINDOWED APPROACH



PARAMETERS

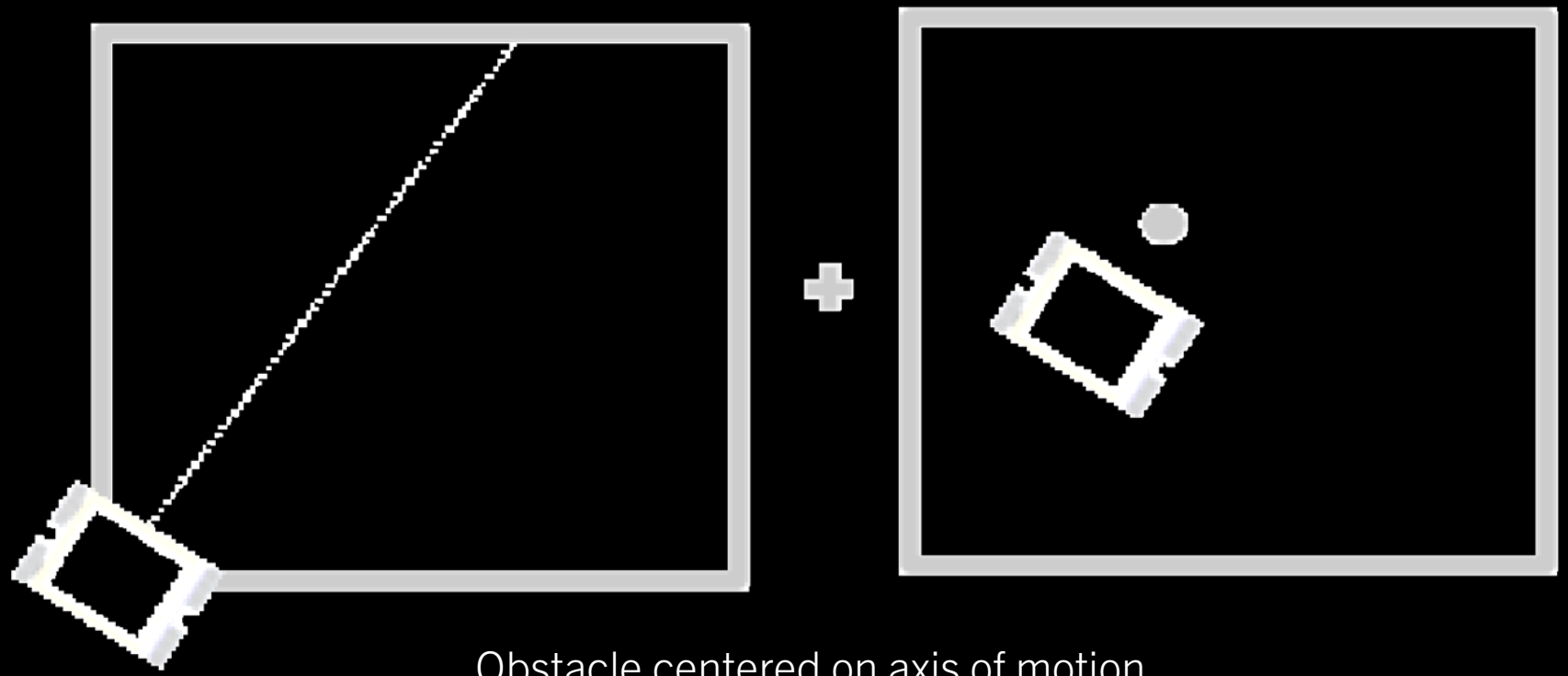
500 meters

5 cm/s

18 hours One-Way

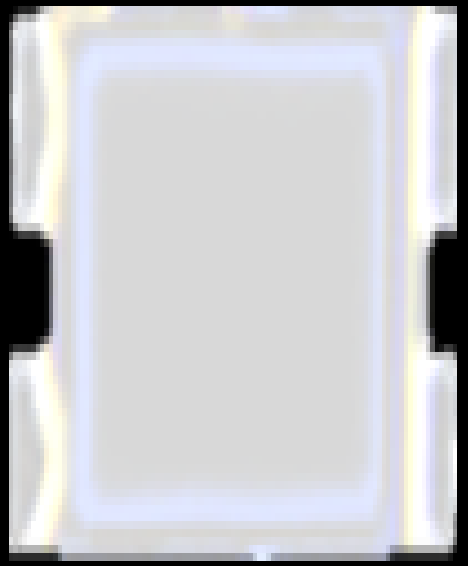
5-meter Window

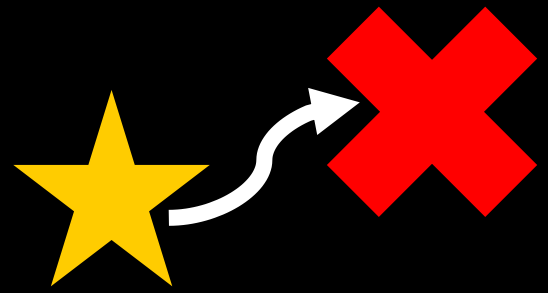
WINDOW: STRAIGHT LINE + ONE OBSTACLE



Obstacle centered on axis of motion.

GOAL OF MODEL/PROOF





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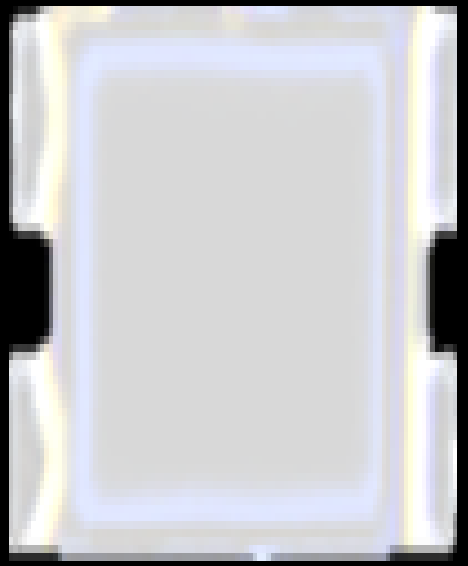

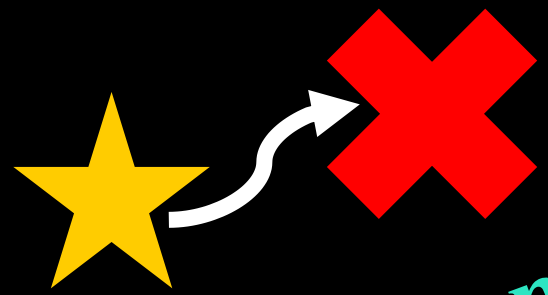

So, custom control OK.

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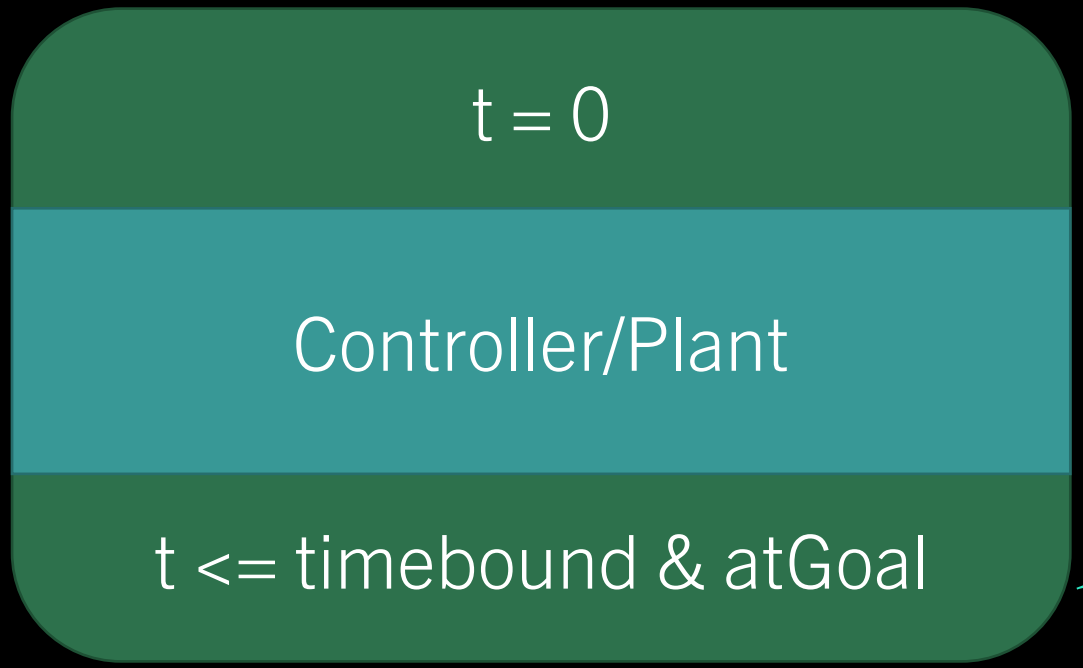
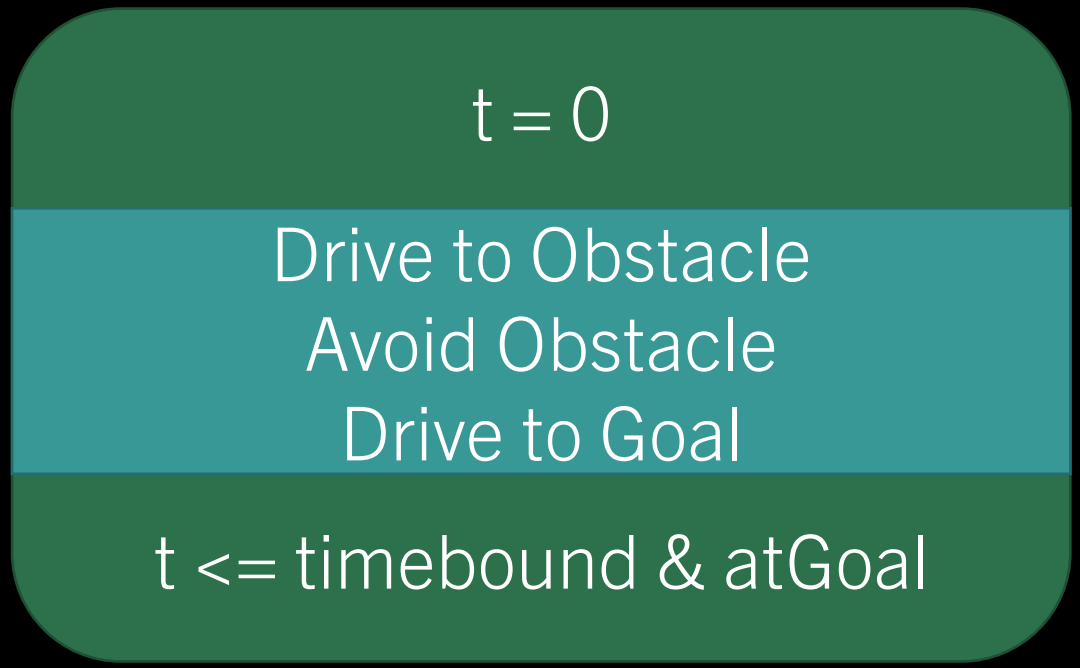
MODEL METHODOLOGY: MEASURING TIME



Proves Straight-Line Bound

MODEL METHODOLOGY: PER-WINDOW, OVERALL



MODEL METHODOLOGY: PER-WINDOW, MODULAR

Drive to Obstacle

Avoid Obstacle

Drive to Goal

MODEL METHODOLOGY:
TWO TYPES OF TIME MEASUREMENTS

Drive to Obstacle

Straight Line Bound

Avoid Obstacle

Straight Line Bound

Drive to Goal

MODEL METHODOLOGY:
TWO TYPES OF TIME MEASUREMENTS

Drive to Obstacle

Avoid Obstacle

Complex Bound

Drive to Goal

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STRAIGHT-LINE BOUND: TO OBSTACLE AND TO GOAL

Dynamics: x' = V, t'=1

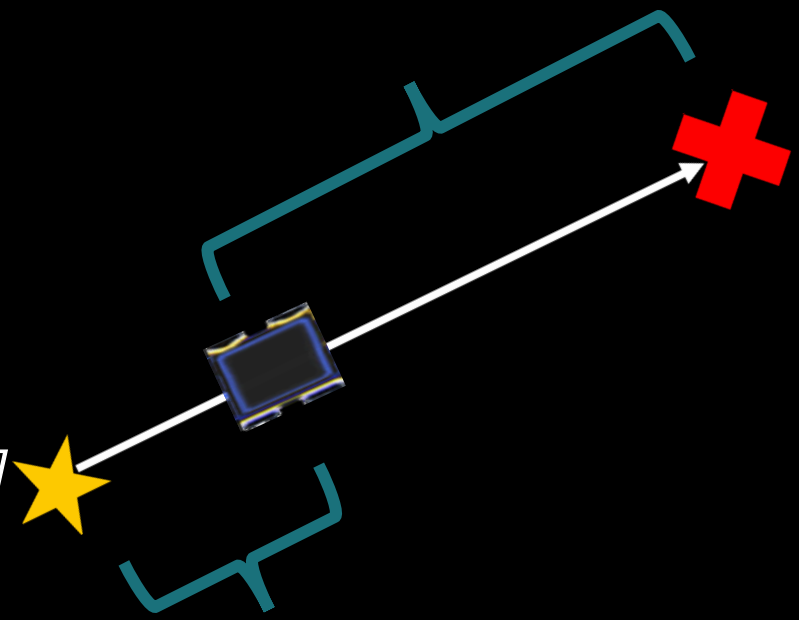
Timing: distanceToGoal <= (timeBound – t)*V

Proof:

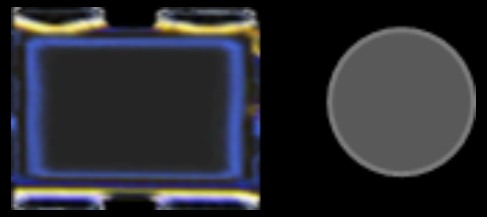
distanceToGoal = startDistance – distanceTraveled *[CUT]*

distanceTraveled = t*V *[CUT]*

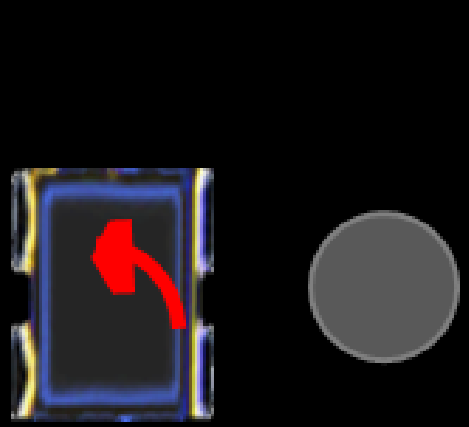
startDistance <= timebound*V *[CUT]*



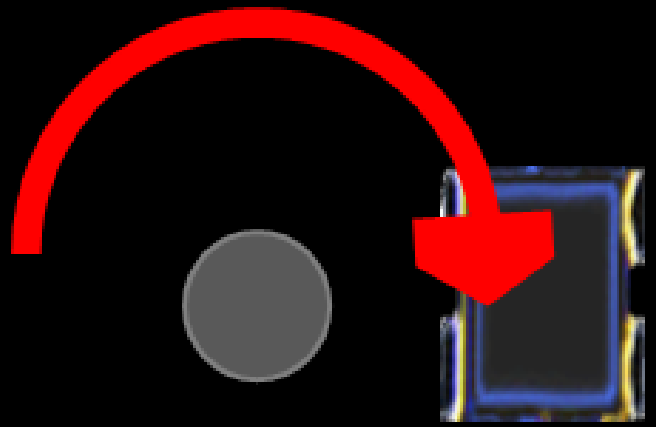
COMPLEX BOUND:
OBSTACLE AVOIDANCE CONTROLLER



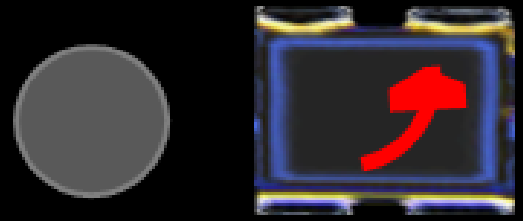
START



90 DEGREE
POINT TURN



ARC AROUND
OBSTACLE



90 DEGREE
POINT TURN

COMPLEX BOUND: TIME 1 OF 2, POINT TURN

Dynamics: dx' = V*dy, dy'=V*dx

orientation variables, V is speed

Timing: t <= 2*(1-dx)/V

dx and dy change by 1 each over the course of a 90-degree turn

Proof:

$dx^2 + dy^2 = 1$ *[CUT]*

t <= 2*(1-dx)/w *[Differential Invariant]*

COMPLEX BOUND:
TIME 2 OF 2, ARC AROUND AN OBSTACLE

Dynamics: Canonical arc dynamics (x, y, dx, dy)

```
{x'=v/trackr*(y-(y-trackr*dy)), y'=-v/trackr*(x-(x-trackr*dx)),
 dx'=v/trackr*(y-(y-trackr*dy))/trackr, dy'=-v/trackr*(x-(x-trackr*dx))/trackr
```

Timing: $t <= 2*(1-dy)/V$

dx and dy change by 2 each over the course of a semi-circle arc

Proof:

$x -(x-trackr*dx))^2 + (y-(y -trackr * dy))^2 = trackr^2$ *[CUT]*

$dx^2 + dy^2 = 1$ *[CUT]*

$t <= 2*(1-dy)/V$

TOTAL TIME:

DISTANCE/V + 2/V + 4/V +2/V

TOTAL TIME:

2/V + DISTANCE/V + 2/V + 4/V +2/V

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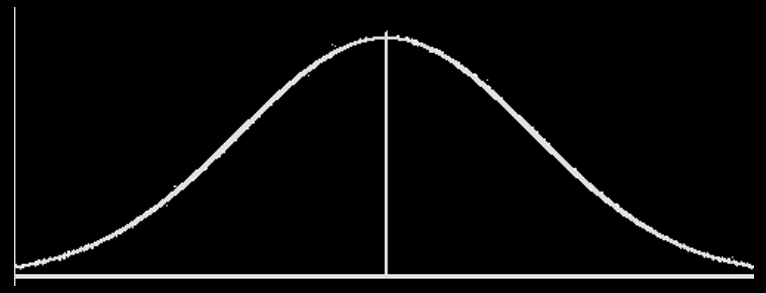
EXTENSIONS

- Compound obstacles:
    - Union of avoiding obstacle and driving straight (to some max)
    - Edit obstacle controller: only point turns and straight drives
    - Obstacle Map
- Consider rock distributions: Converts robot control to simple probability
    - Arc sizes: Larger than largest obstacle expected
    - Time for one obstacle * Number of obstacles expected



THANK YOU FOR LISTENING!

Questions?

IMAGE REFERENCES

- https://mars.nasa.gov/msl/home/
- https://www.cmu.edu/news/stories/archives/2019/february/rover-finds-subterranean-organisms.html
- https://i.pinimg.com/originals/94/3a/73/943a731b972eb744943a59ed2ef5153b.jpg
  https://www.statisticshowto.com/wp-content/uploads/2013/09/normal-distribution-probability.jpg
- Microsoft PowerPoint