Planning in Dynamic Environments Through Temporal Logic Monitoring

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AAAI-16 Workshop on Planning for Hybrid Systems

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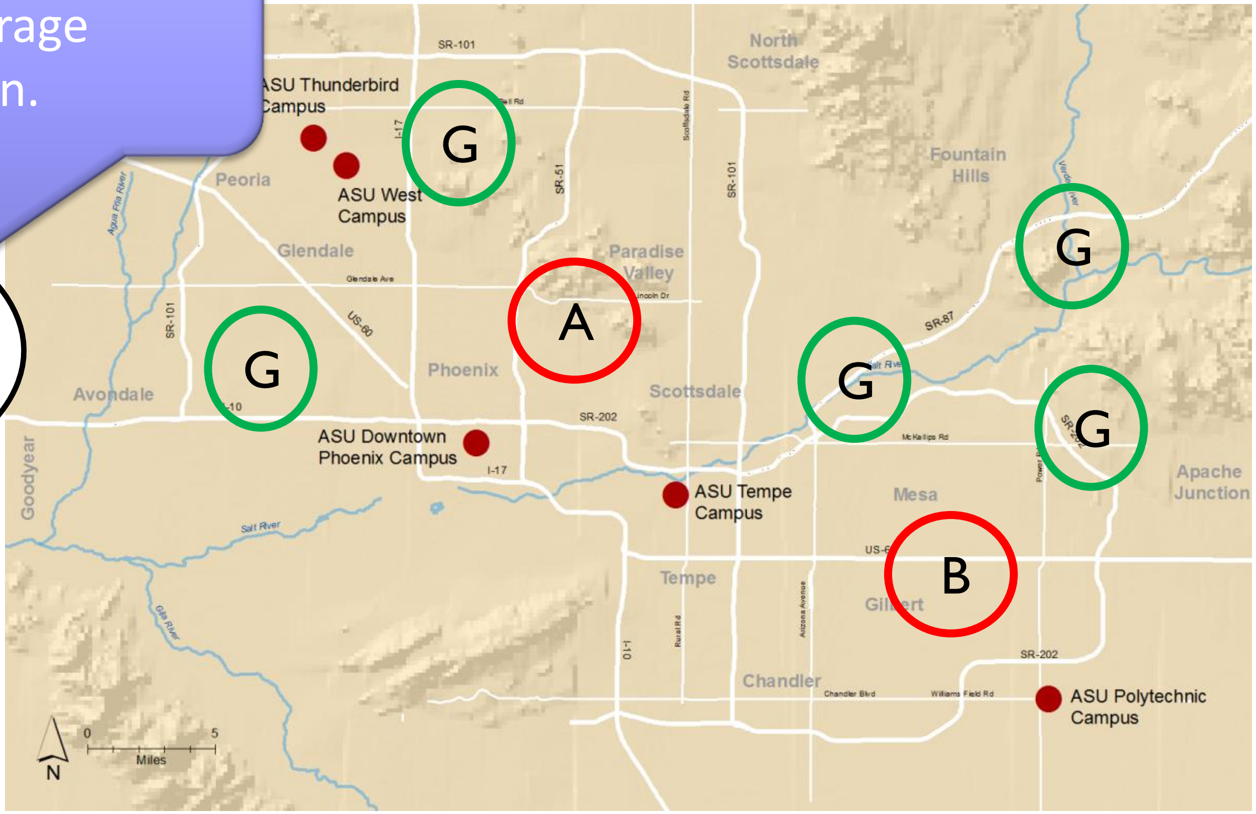
Humans & Robots in the near future

(Please) Drop water on structures A and B and patrol all garage structures G every 15 min.



Humans & Robots in the near future

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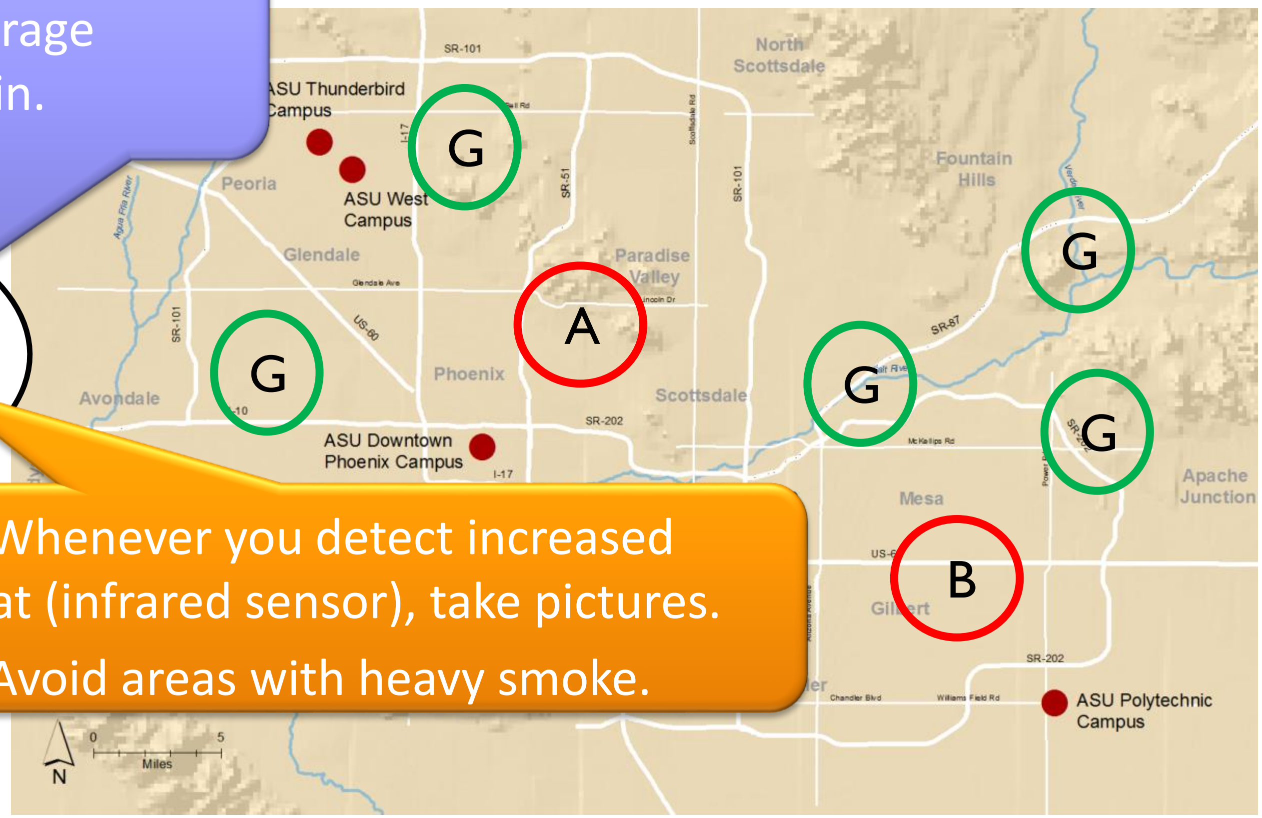
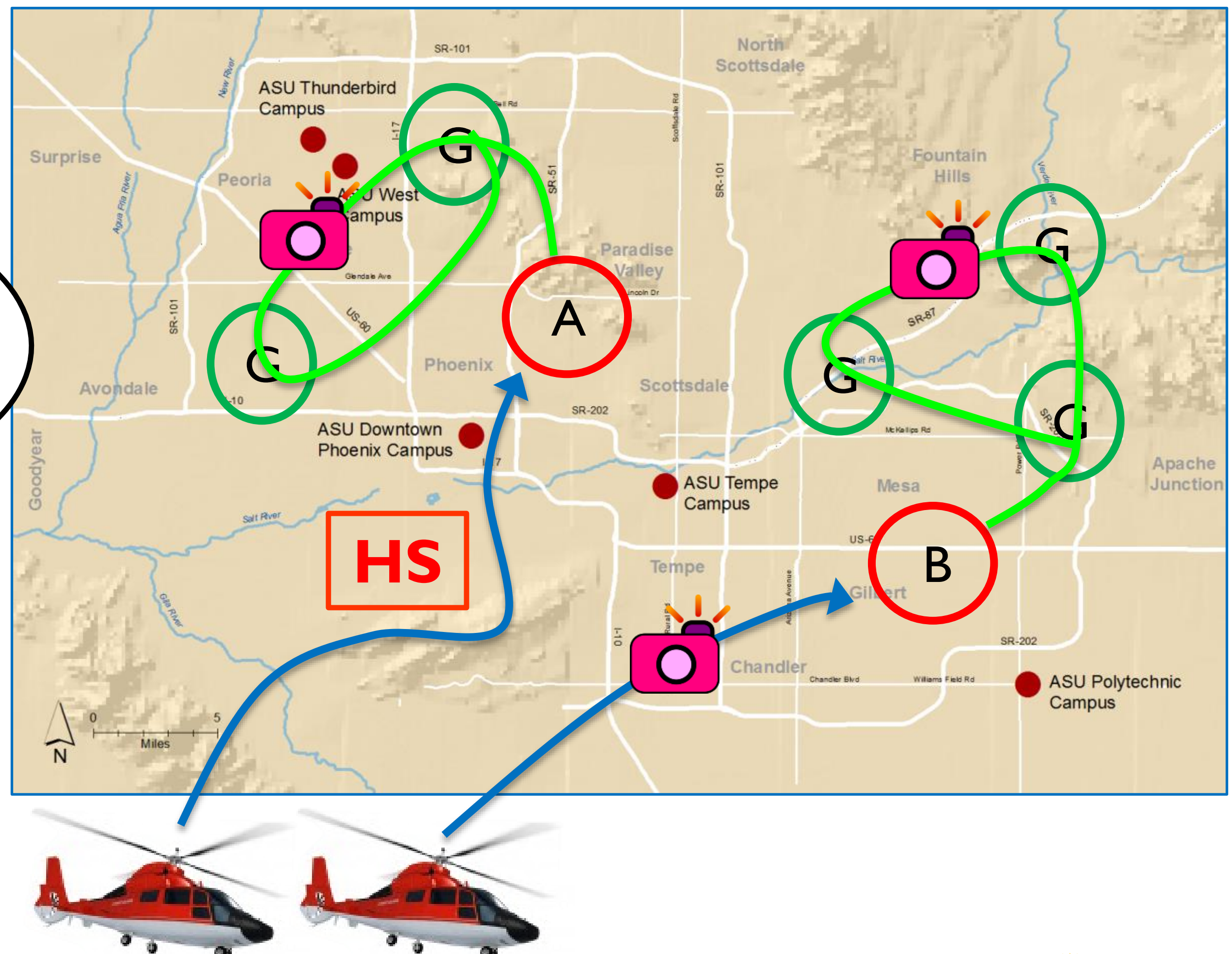


1. Whenever you detect increased heat (infrared sensor), take pictures.
2. Avoid areas with heavy smoke.

Humans & Robots in the near future



Example

Car-like model from the Robotics Toolbox (Corke 2011):

$$\dot{x} = v \cos \theta$$

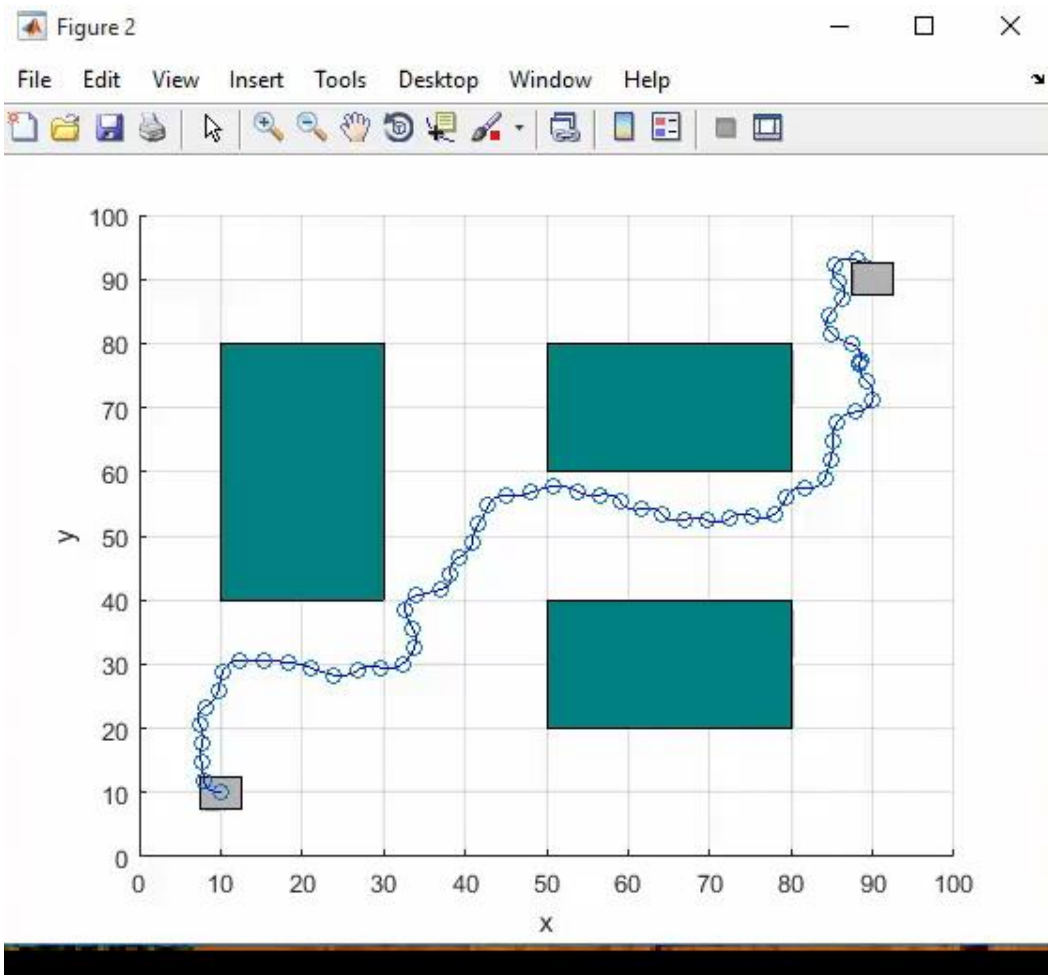
$$\dot{y} = v \sin \theta$$

$$\dot{\theta} = \frac{v}{L} \tan \gamma$$

v: forward speed

L: length of vehicle

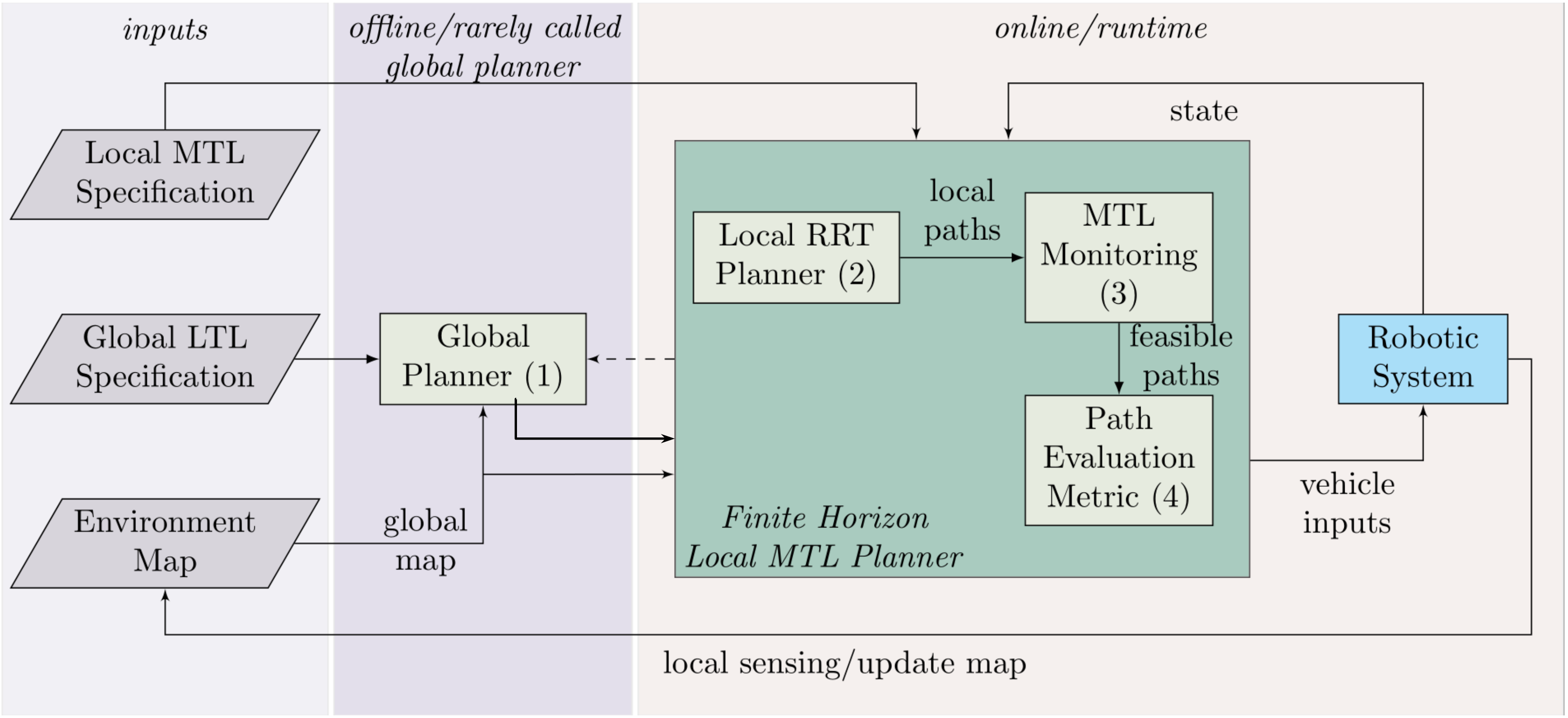
γ: steering angle



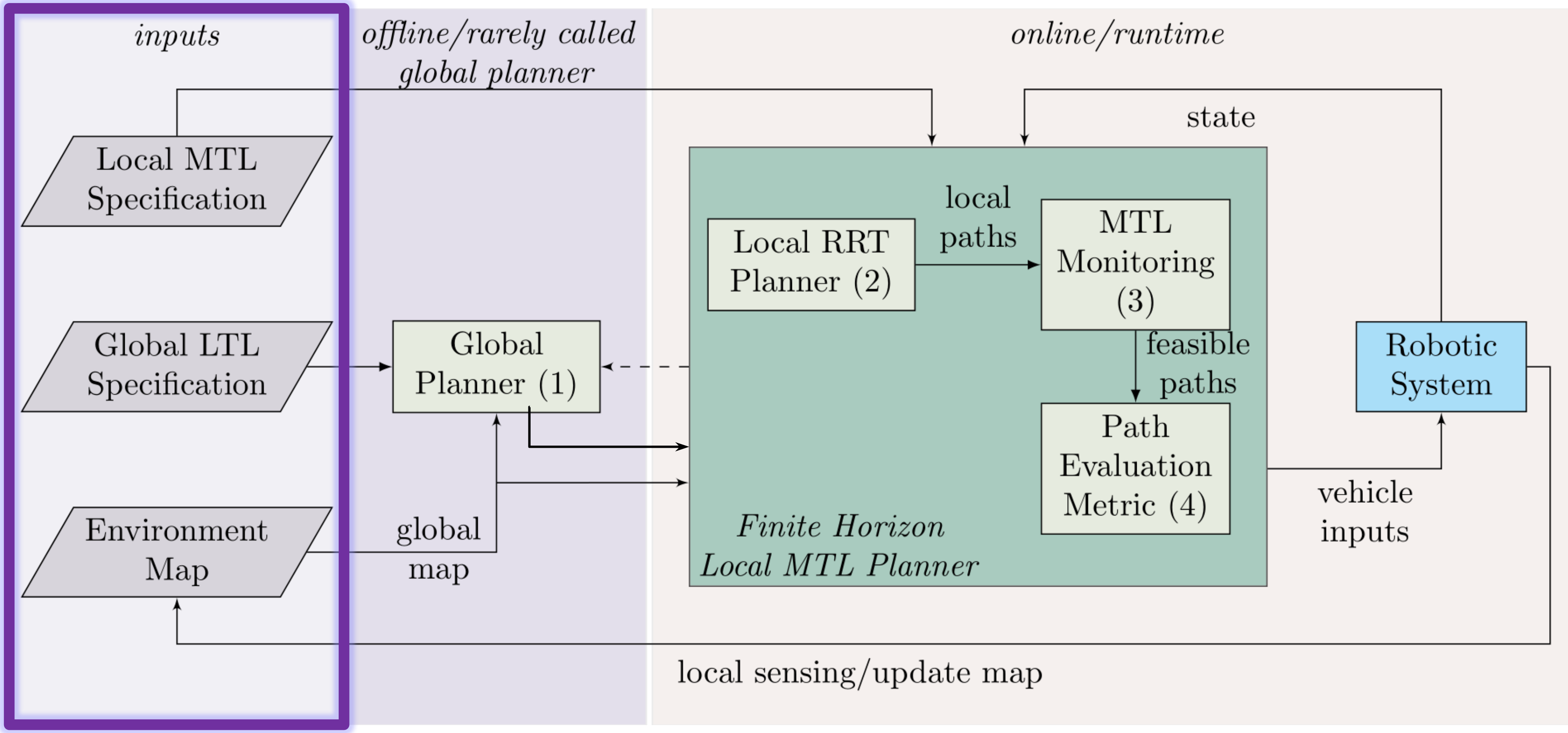
PLAN_{RM} Framework

We present an online planning framework for robotic systems where the environment is dynamically changing and mission compliance specifications may be updated

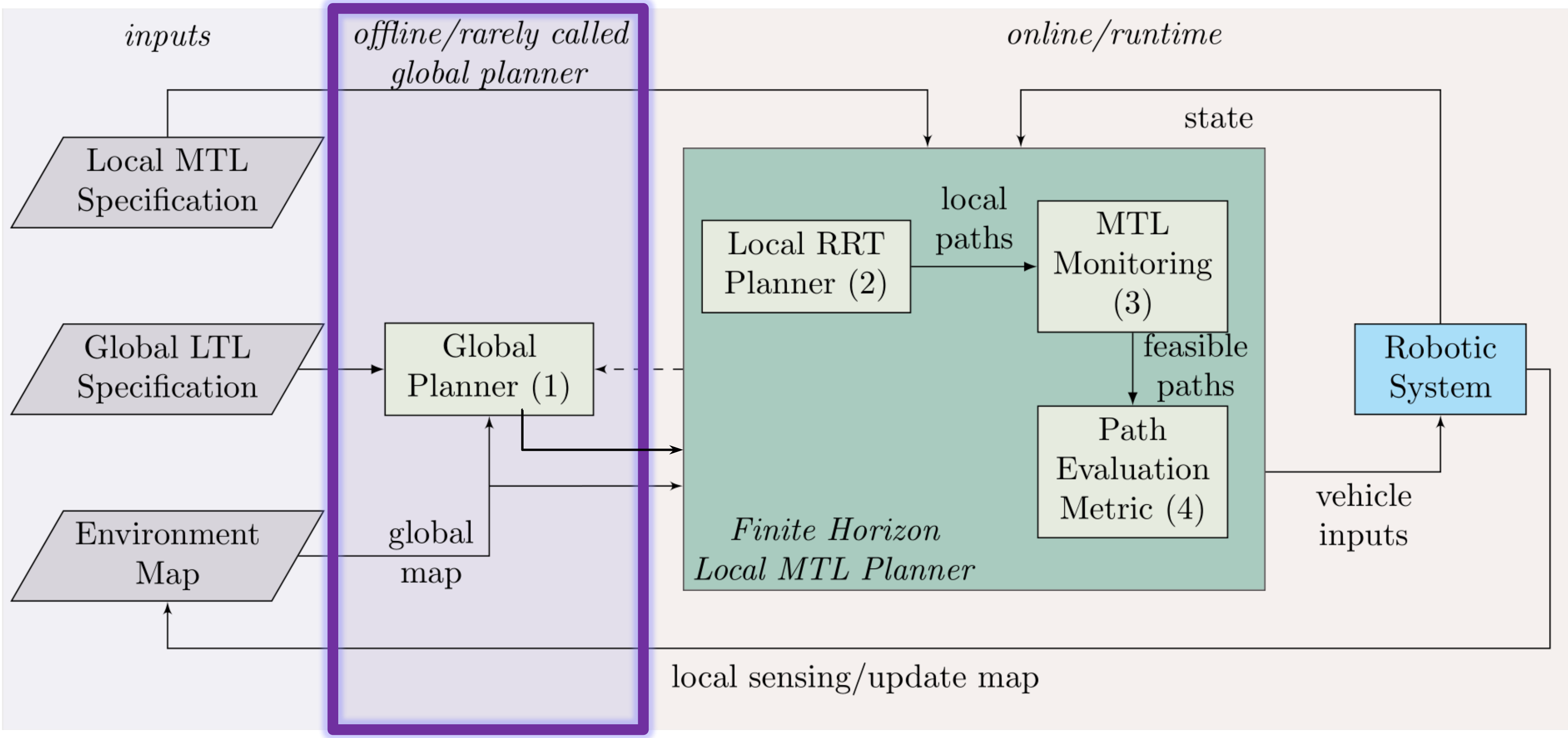
$PLAN_{RM}$ Framework



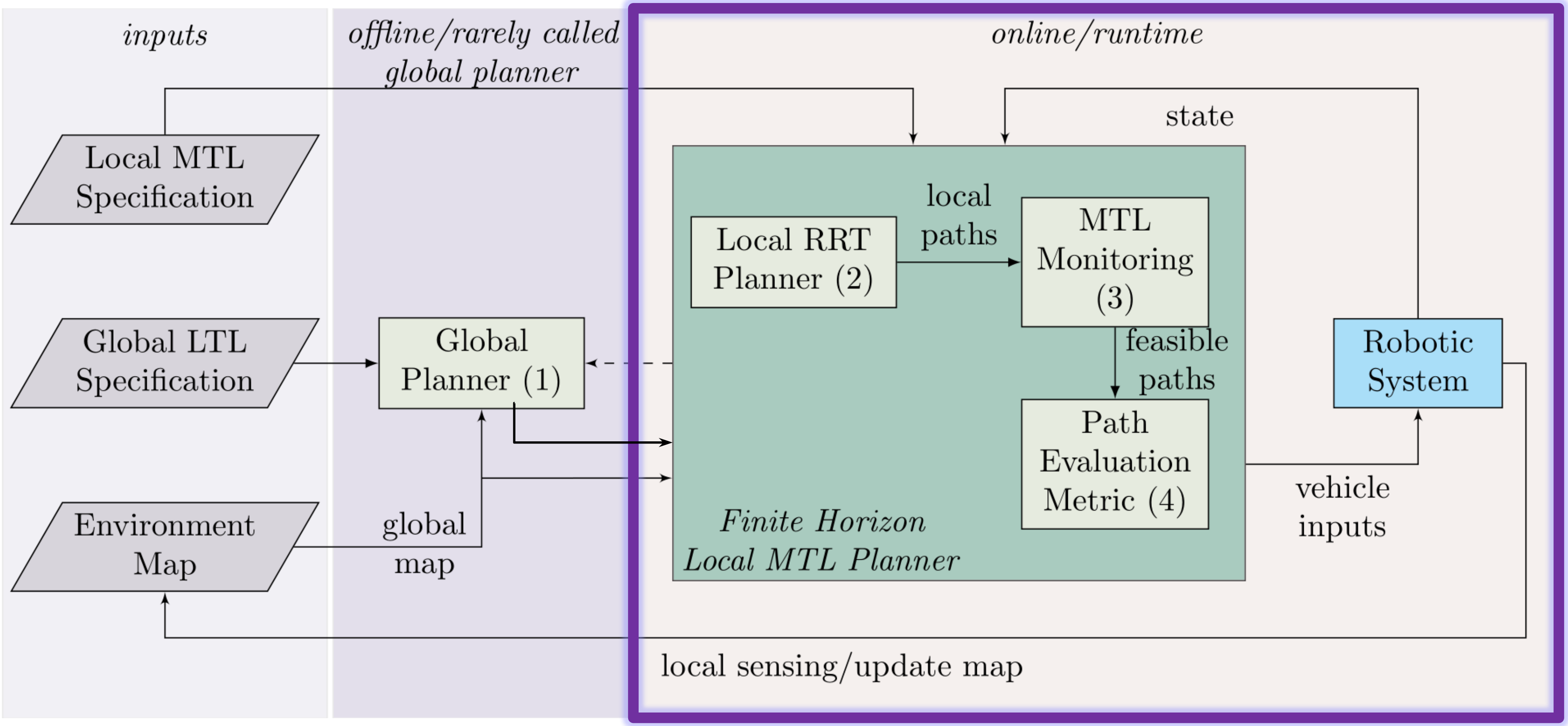
PLAN_{RM} Framework



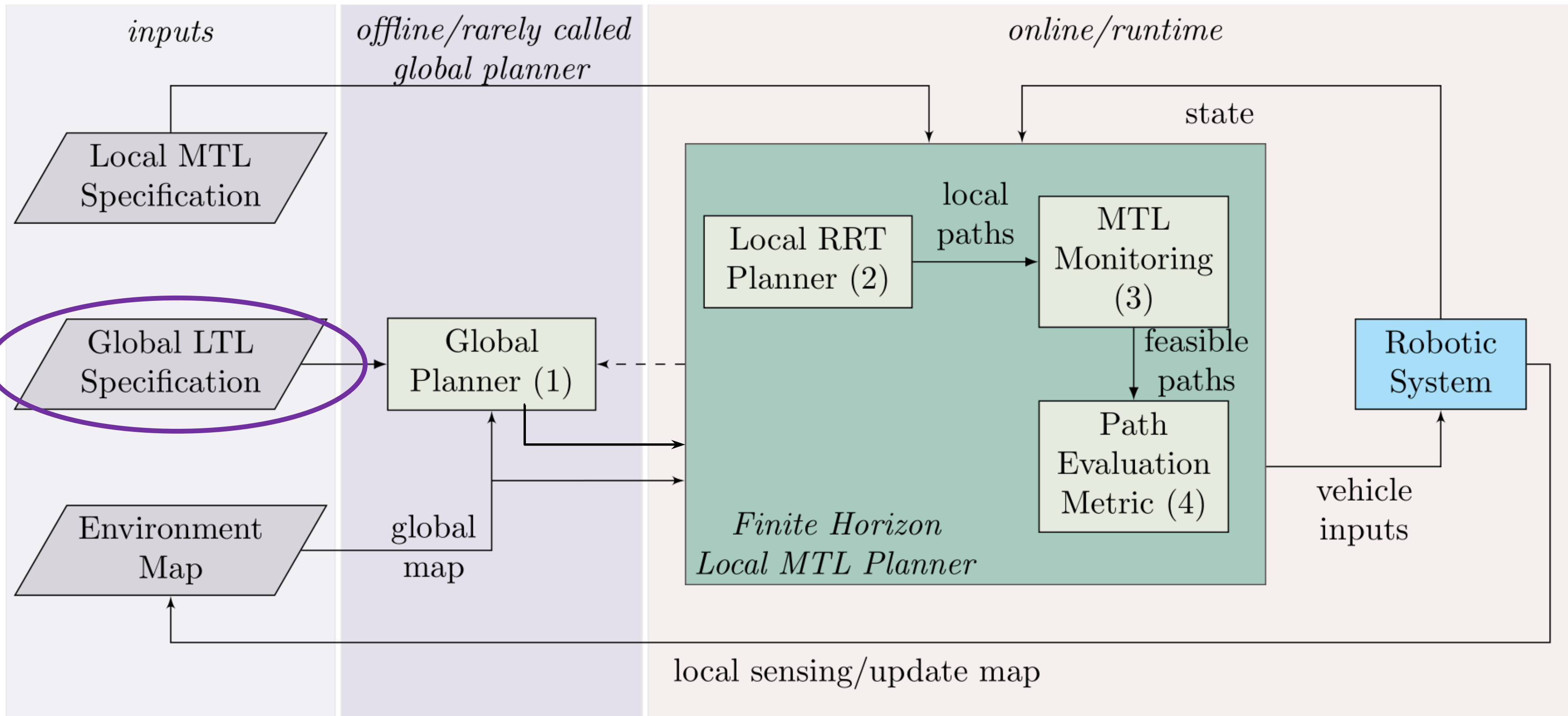
$PLAN_{RM}$ Framework



PLAN$_{RM}$ Framework



PLAN$_{RM}$ Framework



Linear Temporal Logic

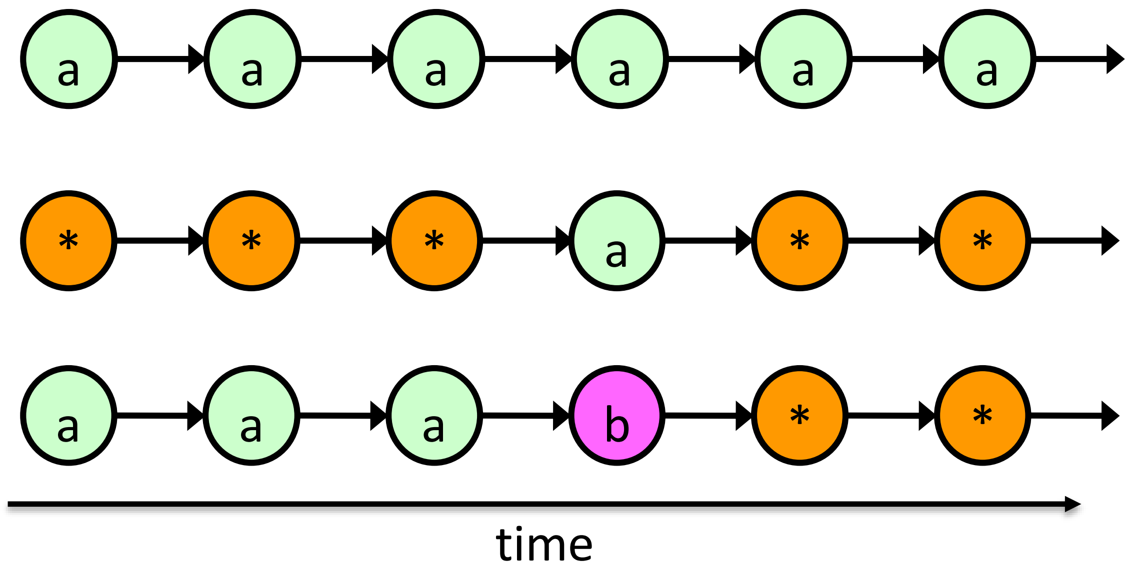
Syntax: Boolean connectives with temporal operators

$$\phi \ ::= \top \mid \neg\phi \mid \phi_1 \vee \phi_2 \mid G\ \phi \mid F\ \phi \mid \phi_1 U \phi_2$$

$G\ a$ - always a

$F\ a$ - eventually a

$a\ U\ b$ - a until b



For example, visit R_1, R_2 and R_3, in that order:

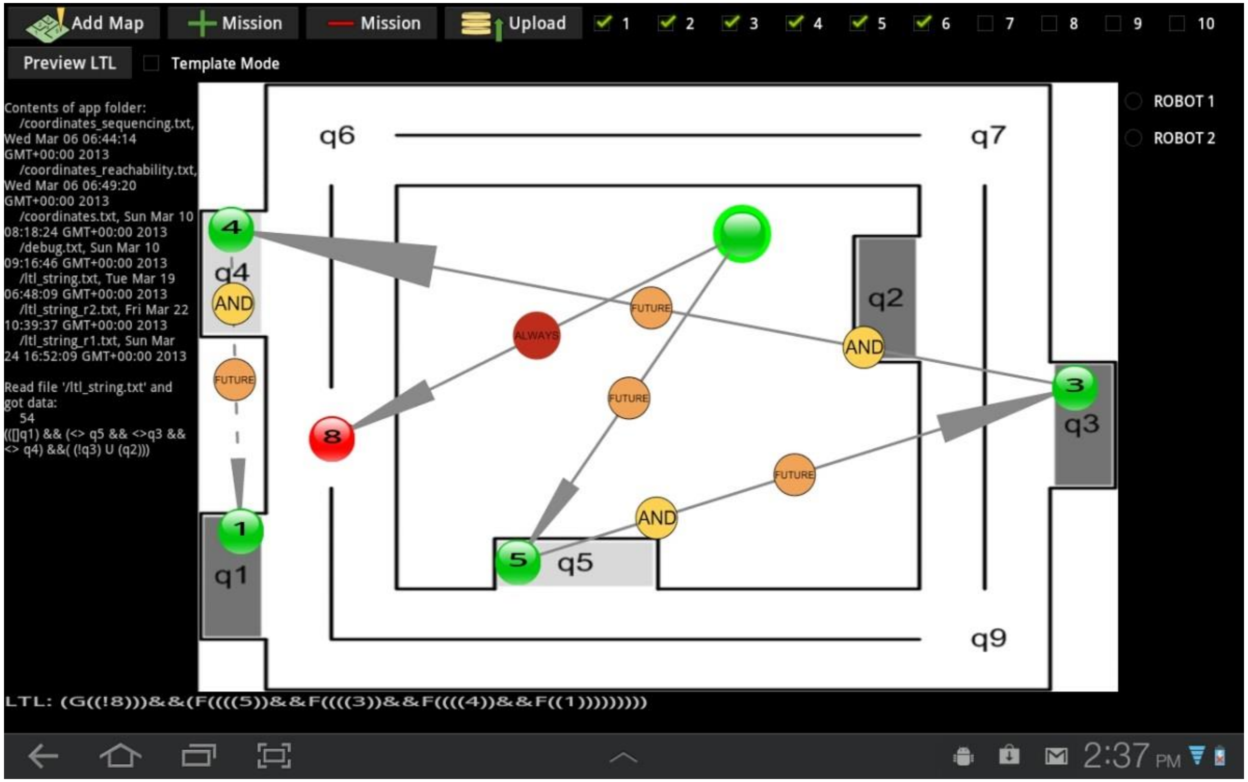
$$F(R_1 \wedge F(R_2 \wedge F R_3))$$

LTL motion and mission planning tool: LTLvis [1]

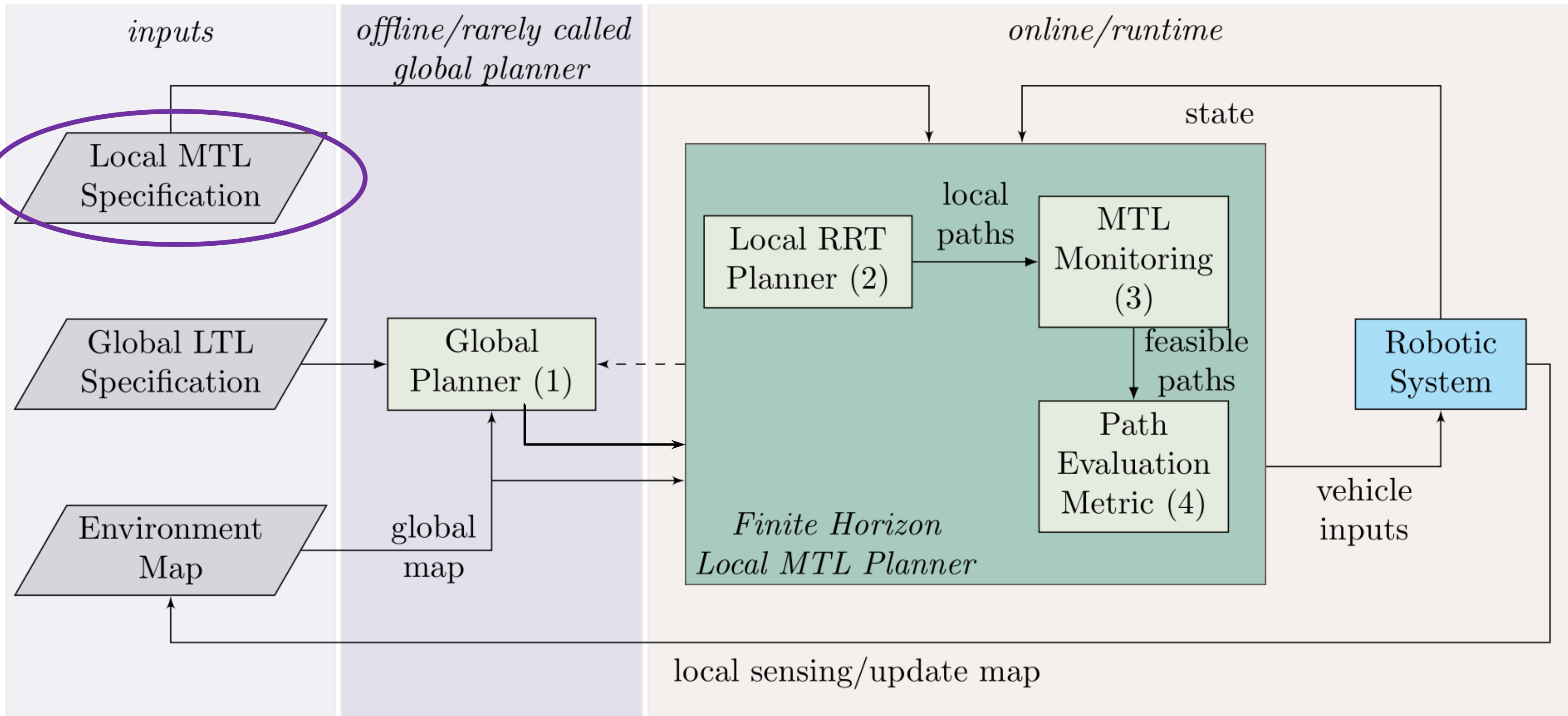
[1] Srinivas, S., Kermani, R., Kim, K., Kobayashi, Y., & Fainekos, G. "A graphical language for LTL motion and mission planning.(ROBIO), 2013.

LTL$_{vis}$

- Translate Visual Specification to LTL
- Design the specification so that it is intuitive, while still maintaining expressivity



PLAN$_{RM}$ Framework



Metric Temporal Logic

Syntax: Boolean connectives with temporal operators

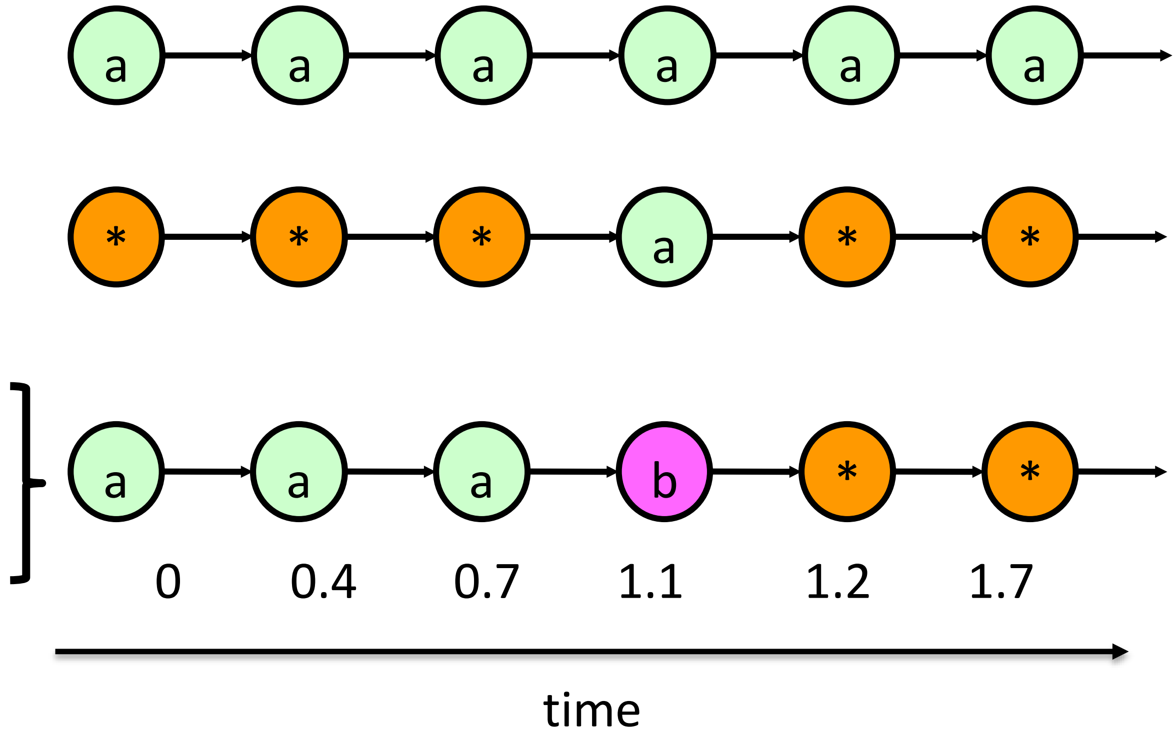
$$\phi \ ::= \top \mid \neg\phi \mid \phi_1 \vee \phi_2 \mid G\ \phi \mid F\ \phi \mid \phi_1 U_I \phi_2$$

$G\ a$ - always a

$F\ a$ - eventually a

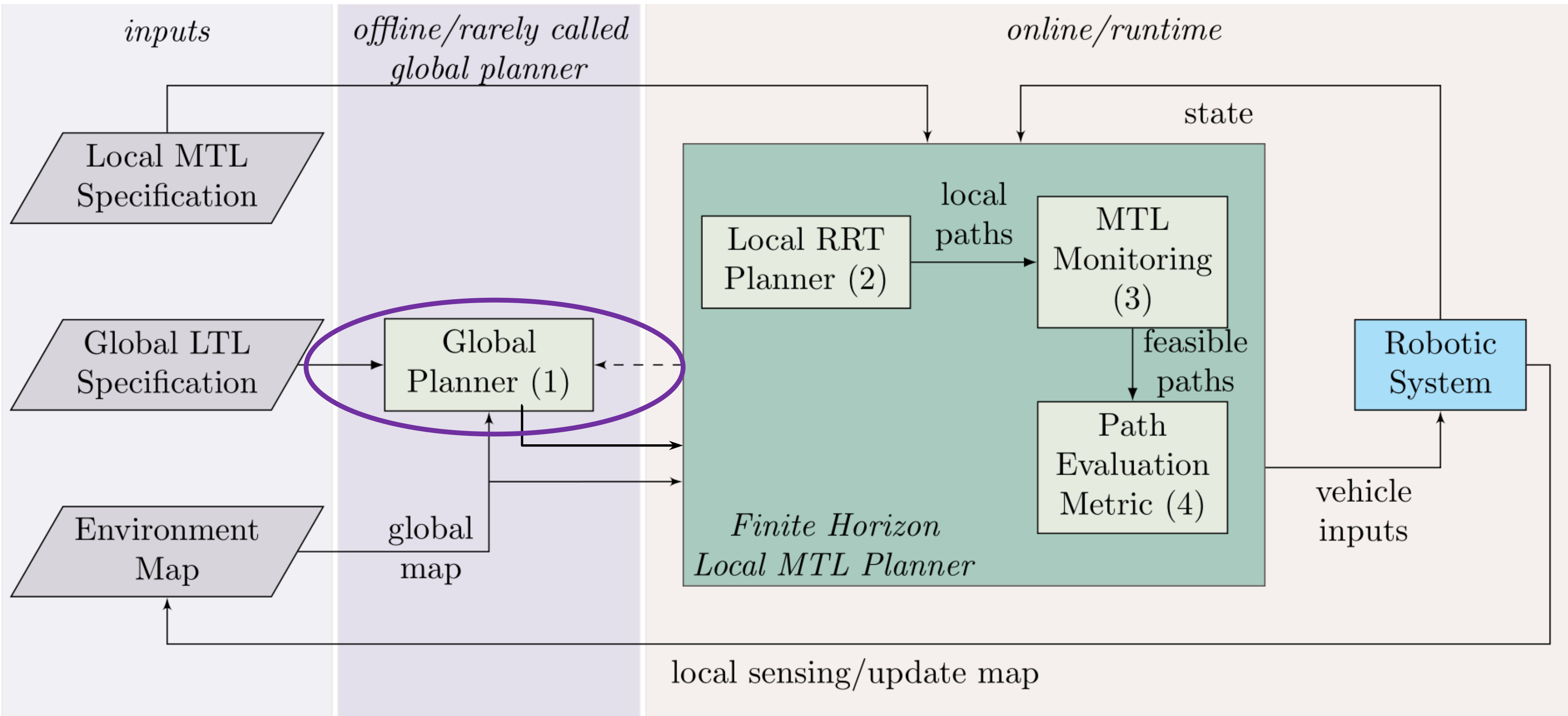
$a\ U\ b$ - a until b

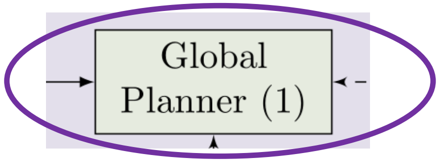
$a\ U_{[1,1.5]}\ b$ - a until b



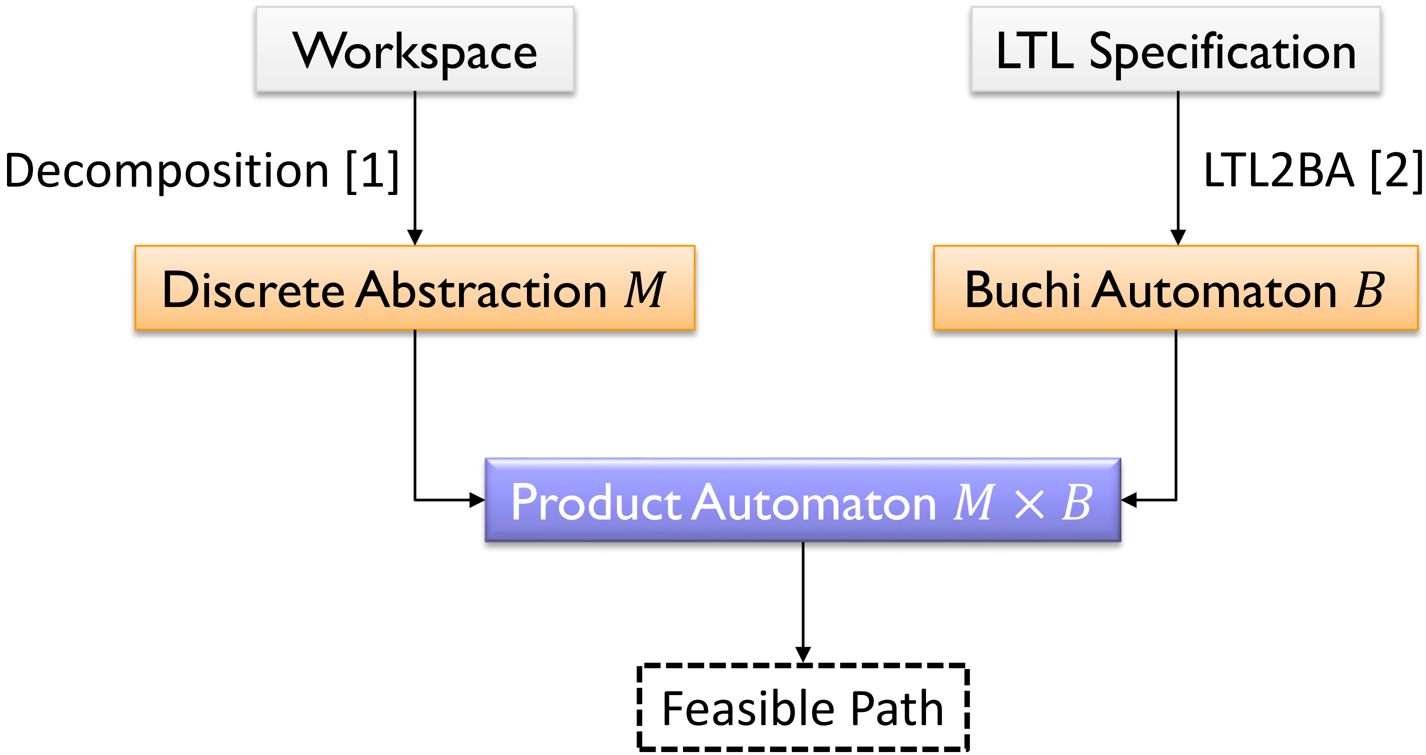
Ex: $F_{[0,5]}(R_1 \wedge F_{[0,4]}(R_2 \wedge F_{[0,8]} R_3))$

PLAN_{RM} Framework



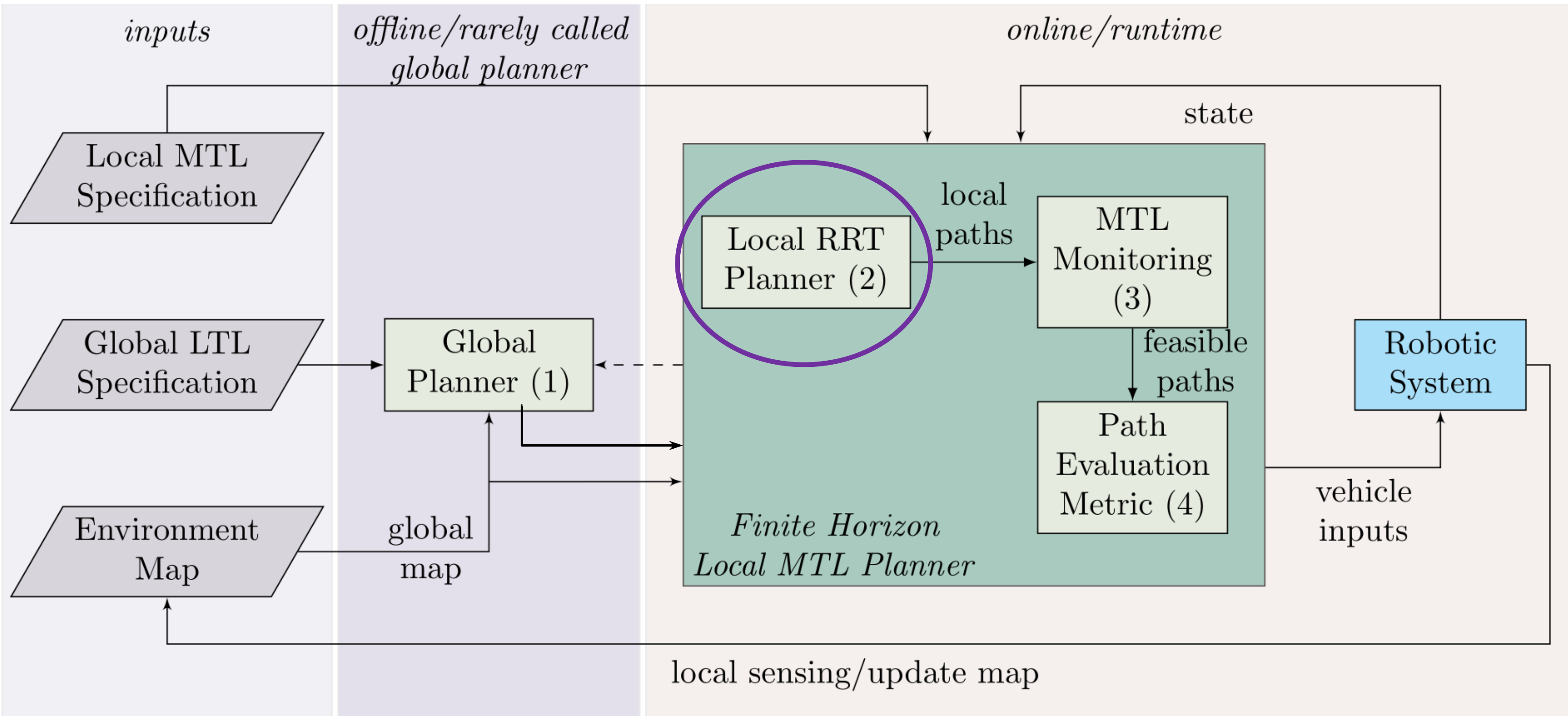


LTL Planning



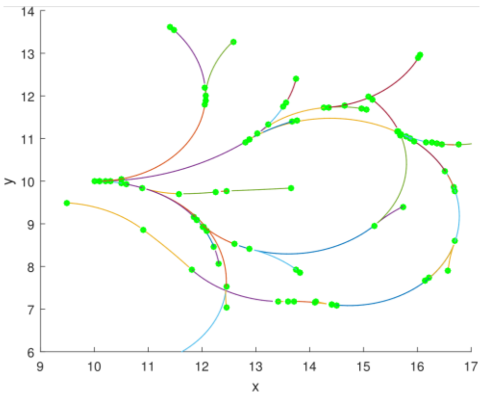
[1] - Fainekos, Georgios E., Hadas Kress-Gazit, and George J. Pappas. "Temporal logic motion planning for mobile robots." *ICRA 2005.*
[2] - Gastin, Paul, and Denis Oddoux. "Fast LTL to Büchi automata translation." CAV, 2001.

PLAN$_{RM}$ Framework

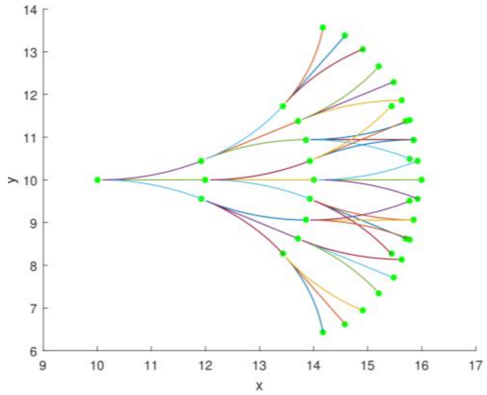


Local Planner

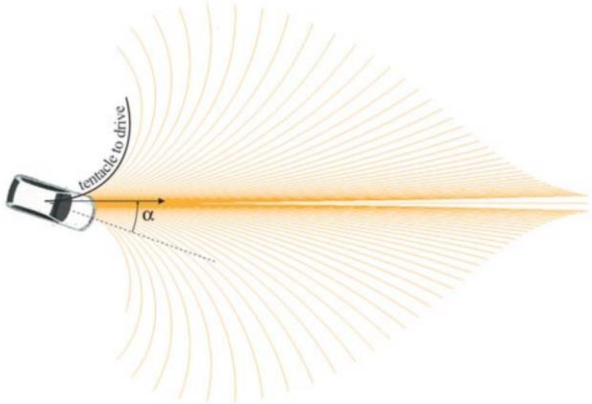
RRT-Based



Spread-Based

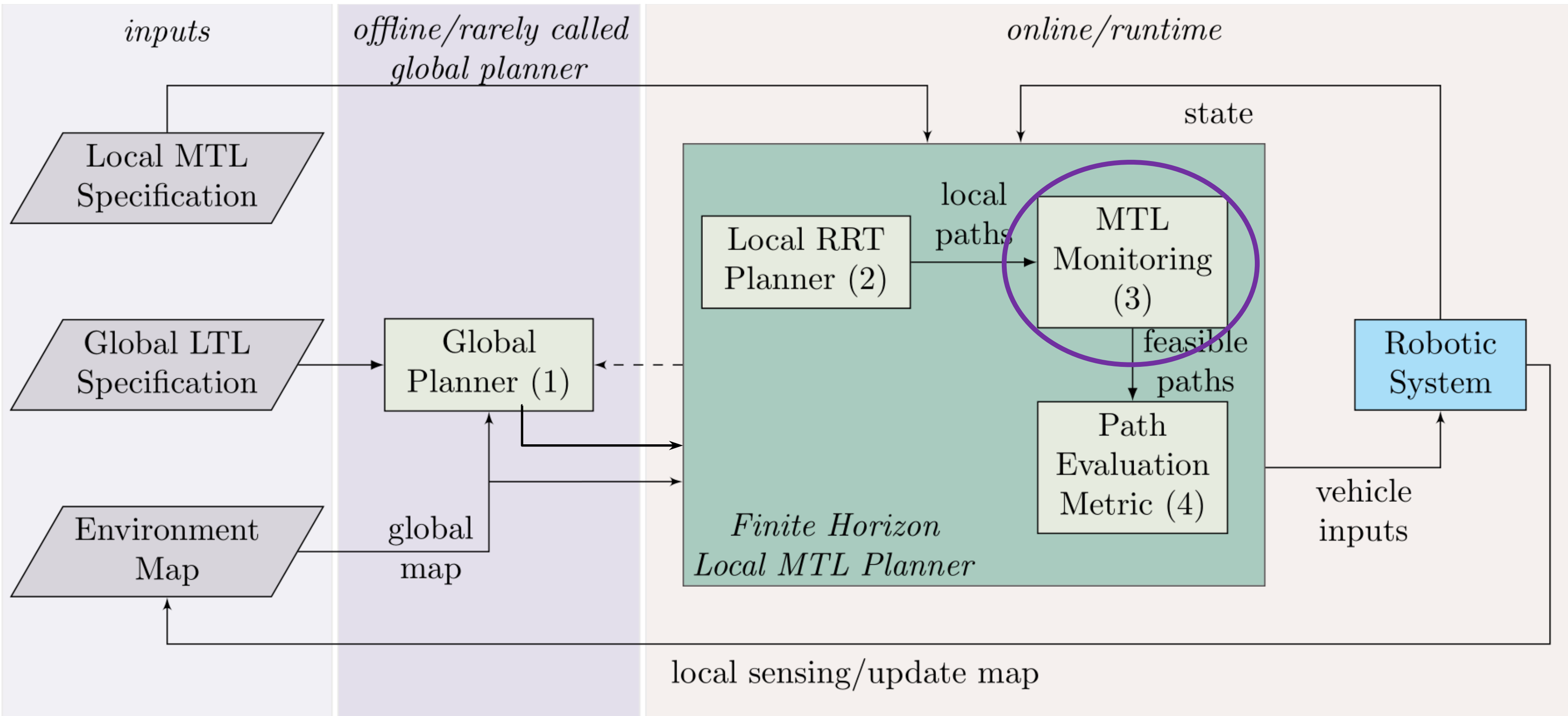


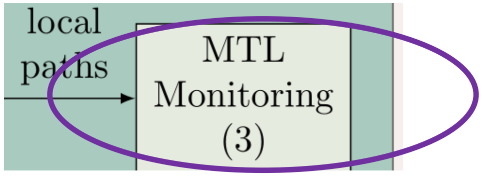
Driving Tentacles [1]



[1] - Von Hundelshausen, Felix, et al. "Driving with tentacles: Integral structures for sensing and motion." Journal of Field Robotics, 2008.

$PLAN_{RM}$ Framework





MTL Monitoring

1. Determine window size

MTL Specification $R_1 \rightarrow F_{[0,2]} R_2$

↓

Monitoring Algorithm [1]

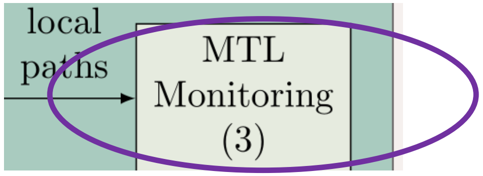
↓

Window Size Hrz = 2

↓

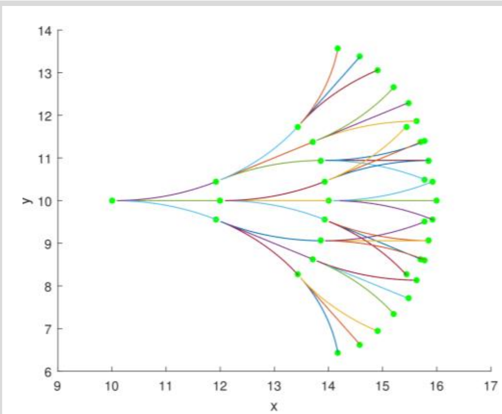
Local Planner

[1] Dokhanchi, A.; Hoxha, B.; and Fainekos, G. On-line monitoring for temporal logic robustness. RV 2014



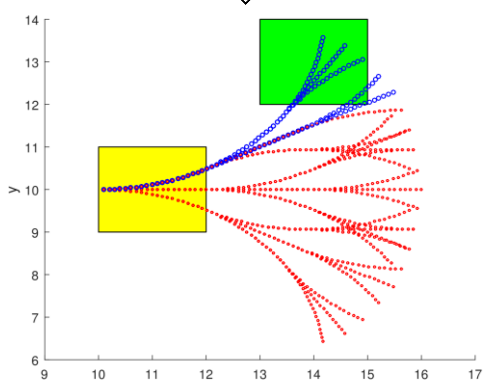
MTL Monitoring

2. Classify Local Paths

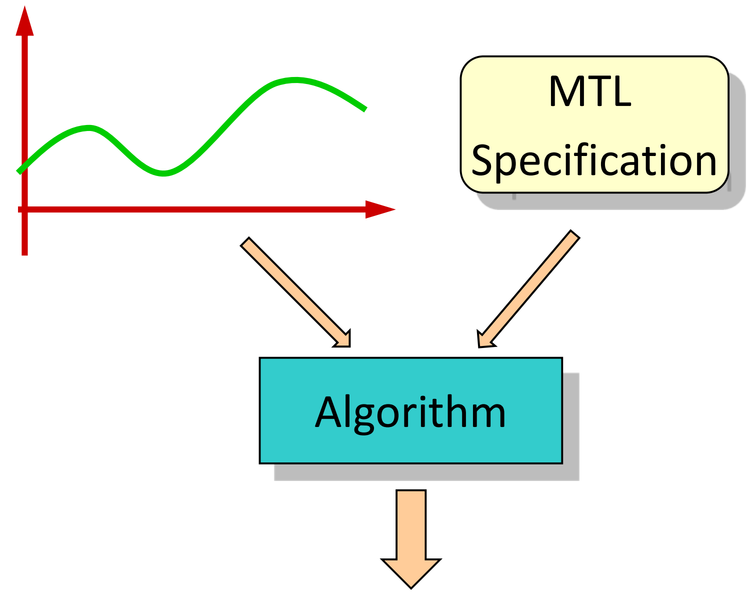


MTL Specification

Ex: $R_1 \rightarrow F_{[0,2]} R_2$



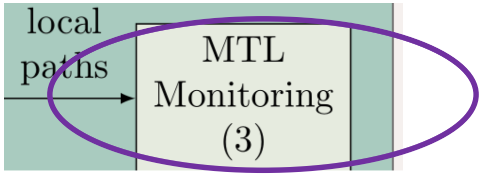
Robustness Estimate



Robustness

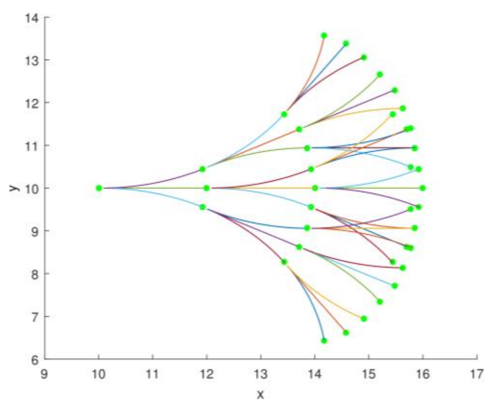
positive robustness → signal satisfies the formula

negative robustness → signal falsifies the formula



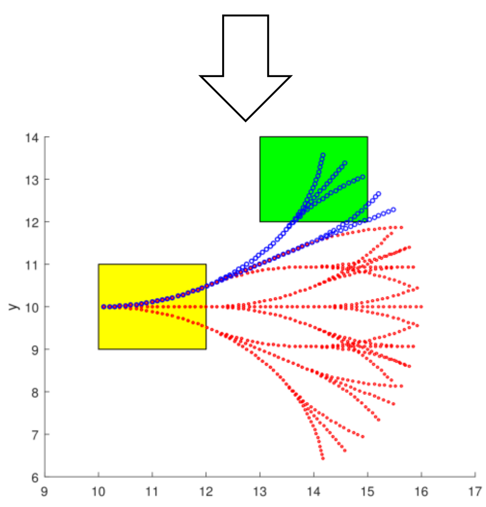
MTL Monitoring

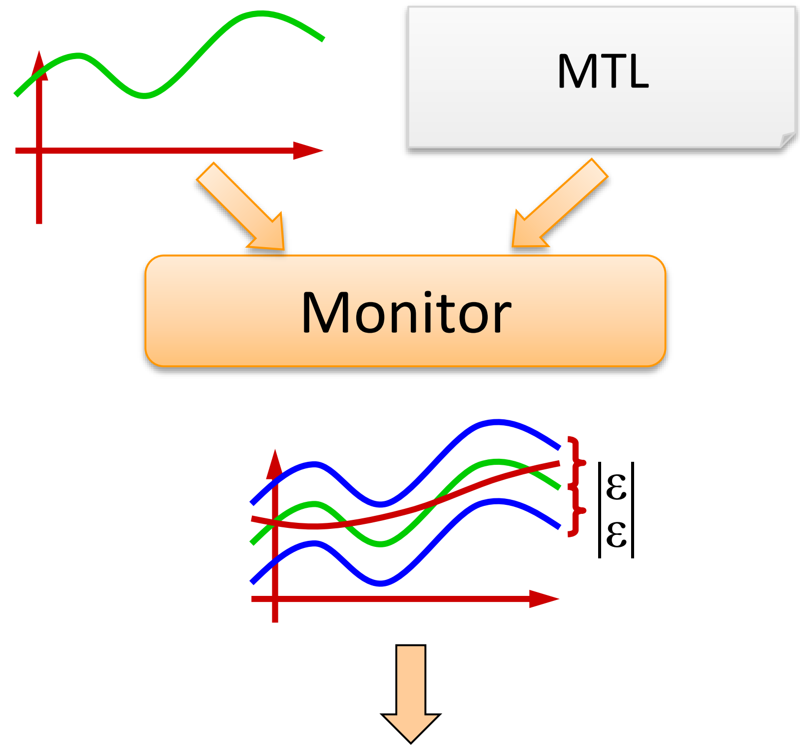
2. Classify Local Paths



MTL Specification

Ex: $R_1 \rightarrow F_{[0,2]} R_2$



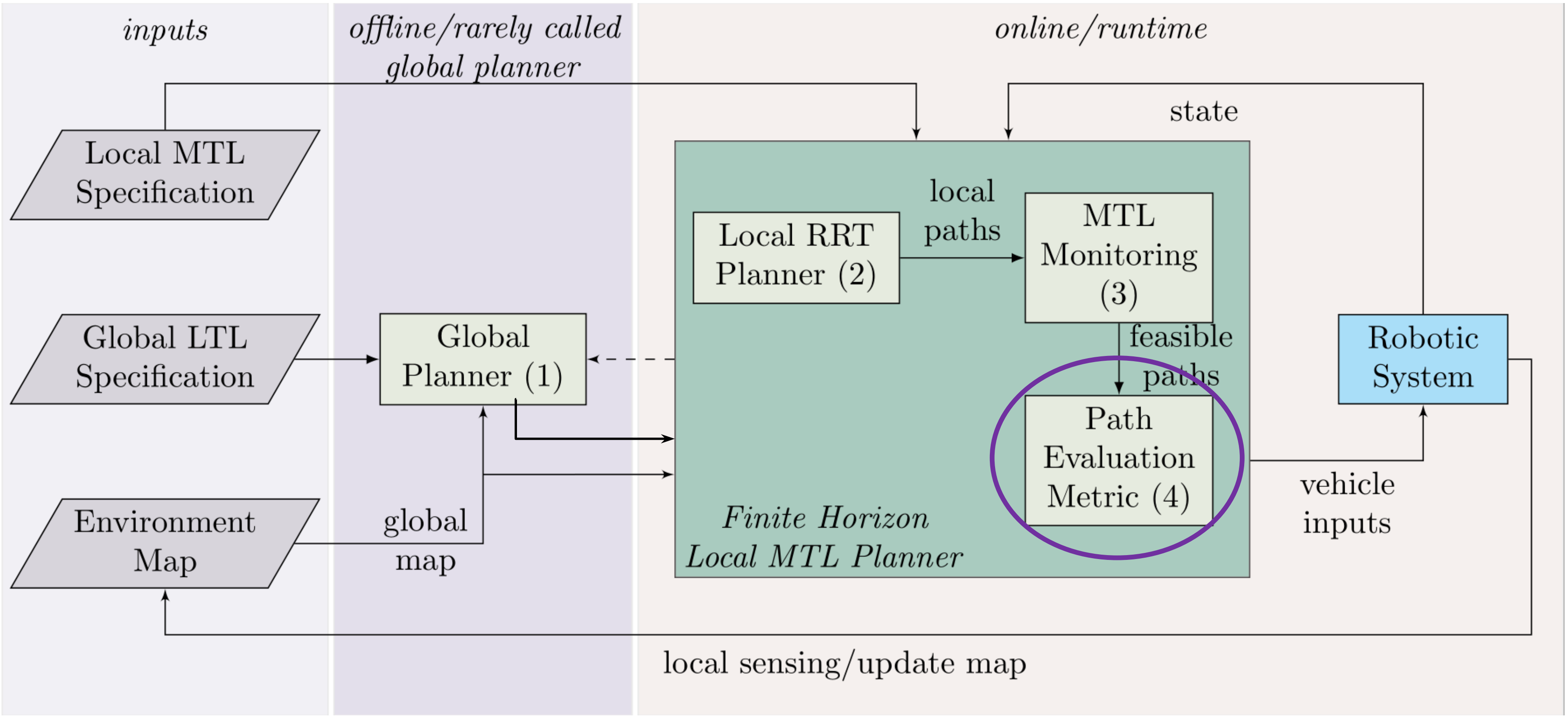


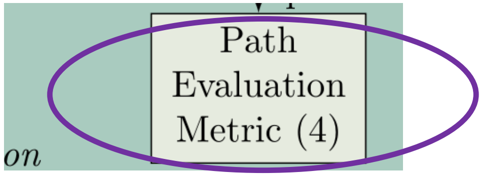
Robustness: ε ∈ R U{±∞}

positive robustness → signal satisfies the formula

negative robustness → signal falsifies the formula

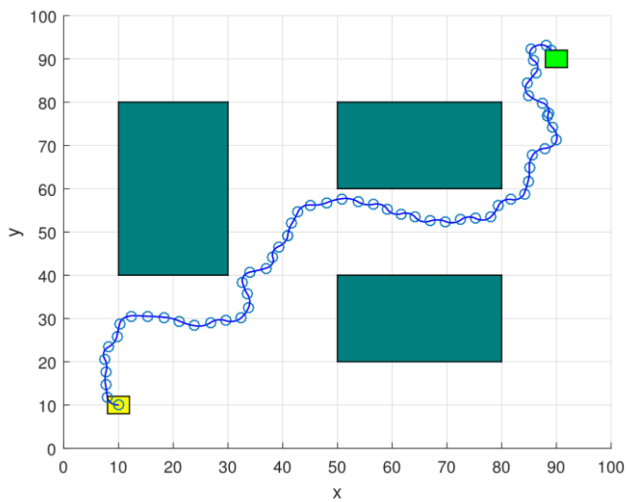
$PLAN_{RM}$ Framework



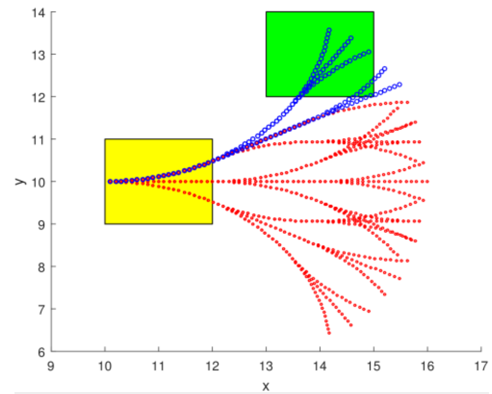


Path Evaluation Metric

1. Global Path



2. Local Paths



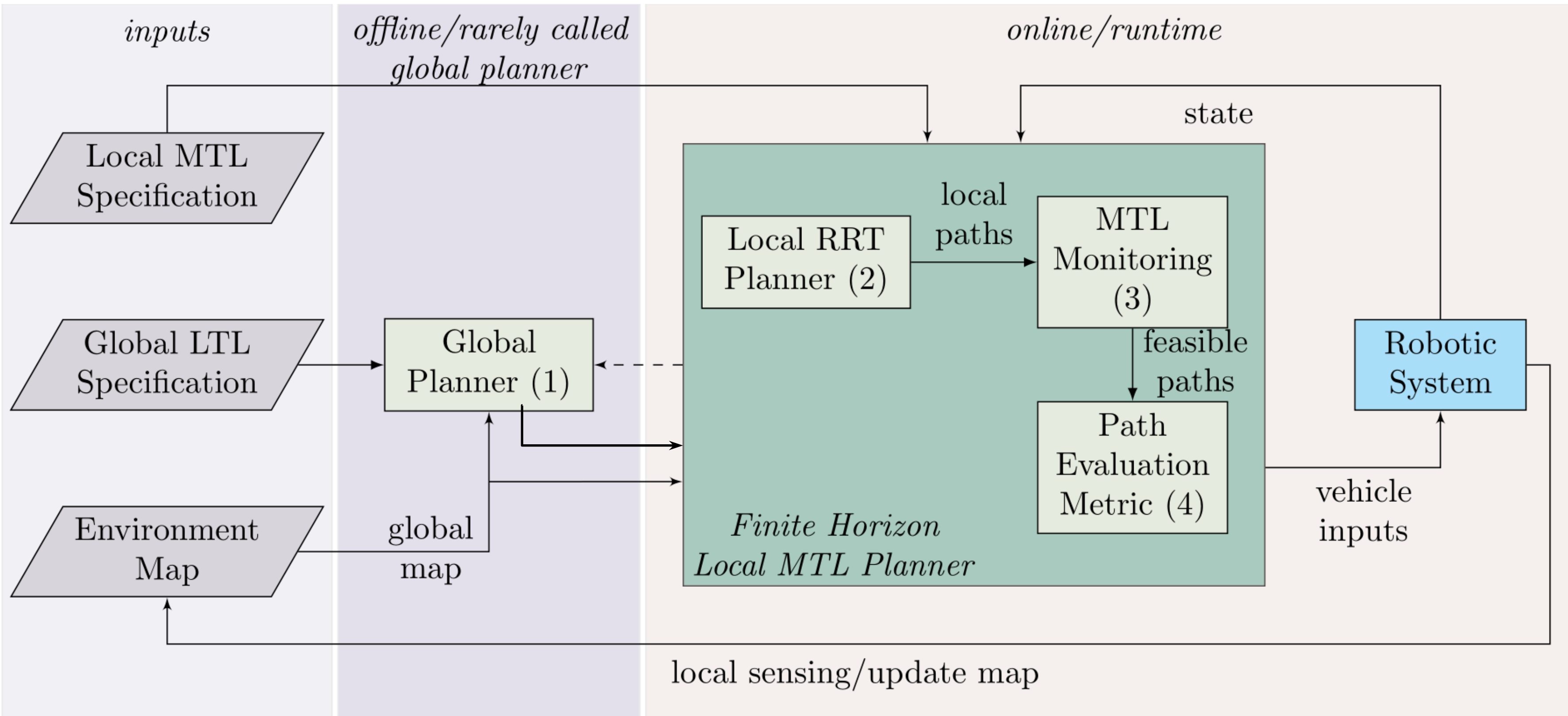
Which path should I choose?

Selection Criterion:

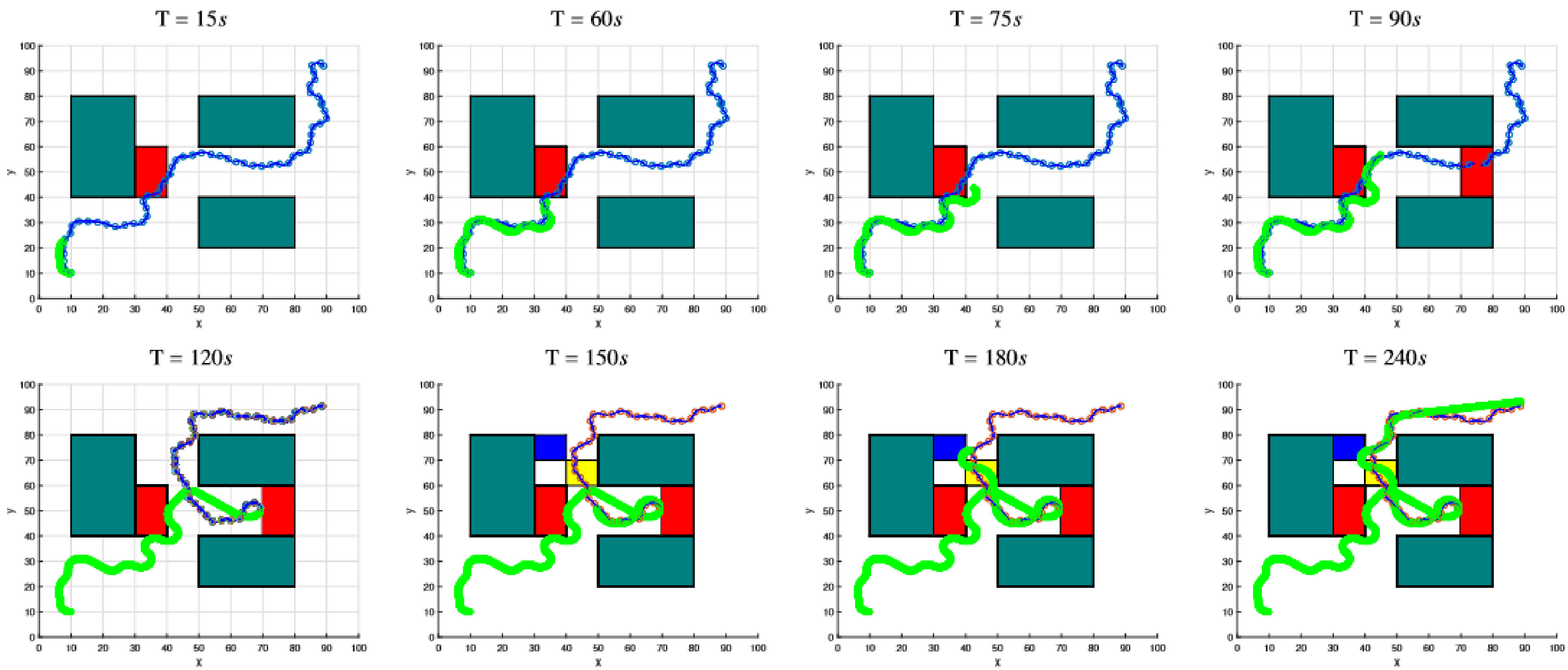
$$\max_{p \in feasiblePaths} c_1 \times Robustness\ Estimate(p, \phi) + c_2 \times Similarity\ Measure(p)$$

Where $\sum c_i = 1$

$PLAN_{RM}$ Framework



Example



Future Work

- Detect Livelock Situations
- Other candidates for the selection criterion
- Maintain future obligations when updating global plan
- Utilize $PLAN_{HS}$ with a complex hybrid system

Related Work

- Motion planning over LTL specifications
  - Plaku, E., and McMahon, J. 2013. Combined mission and motion planning to enhance autonomy of underwater vehicles operating in the littoral zone.
  - Plaku, E.; Kavraki, L. E.; and Vardi, M. Y. 2009. Falsification of LTL safety properties in hybrid systems.
  - Loizou, S. G., and Kyriakopoulos, K. J. 2004. Automatic synthesis of multi-agent motion tasks based on LTL specifications.
- Planning with MTL specifications
  - Kabanza, F. Synchronizing multiagent plans using temporal logic specifications. 1995.
  - Karaman, S., and Frazzoli, E. Vehicle routing problem with metric temporal logic specifications. 2008b.
- Controller synthesis for motion planning of dynamical systems with TL
  - Fainekos, Georgios E., Hadas Kress-Gazit, and George J. Pappas. "Temporal logic motion planning for mobile robots." ICRA 2005.
  - Kloetzer, M., and Belta, C. “Temporal logic planning and control of robotic swarms by hierarchical abstractions”. Robotics, IEEE Tran. 2007.
- Online Planning with LTL specifications
  - Ding, X.; Lazar, M.; and Belta, C. LTL receding horizon control for finite deterministic systems. 2014.

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Thank you!