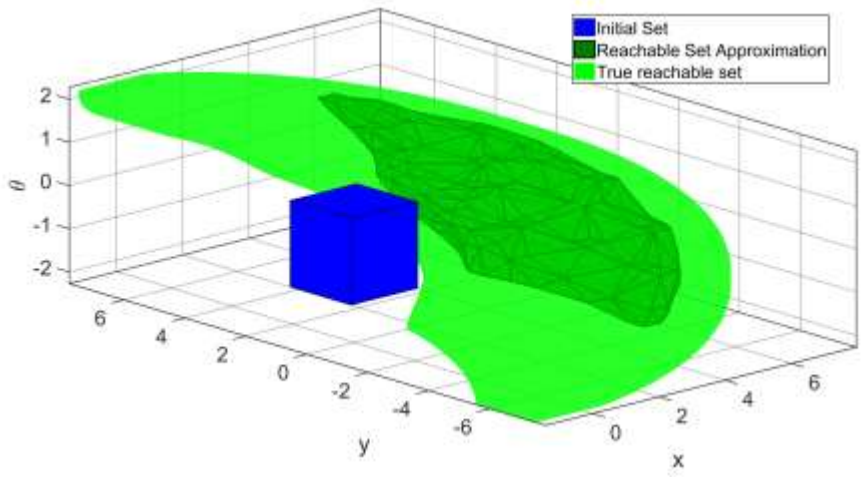
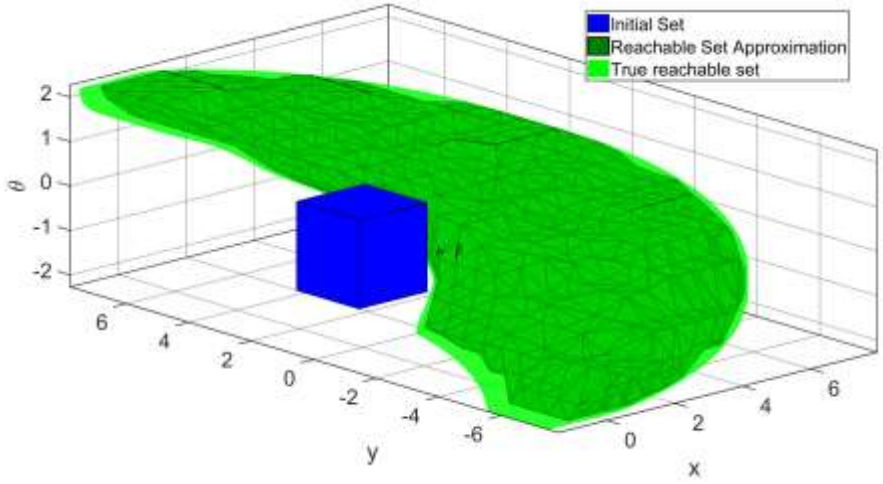




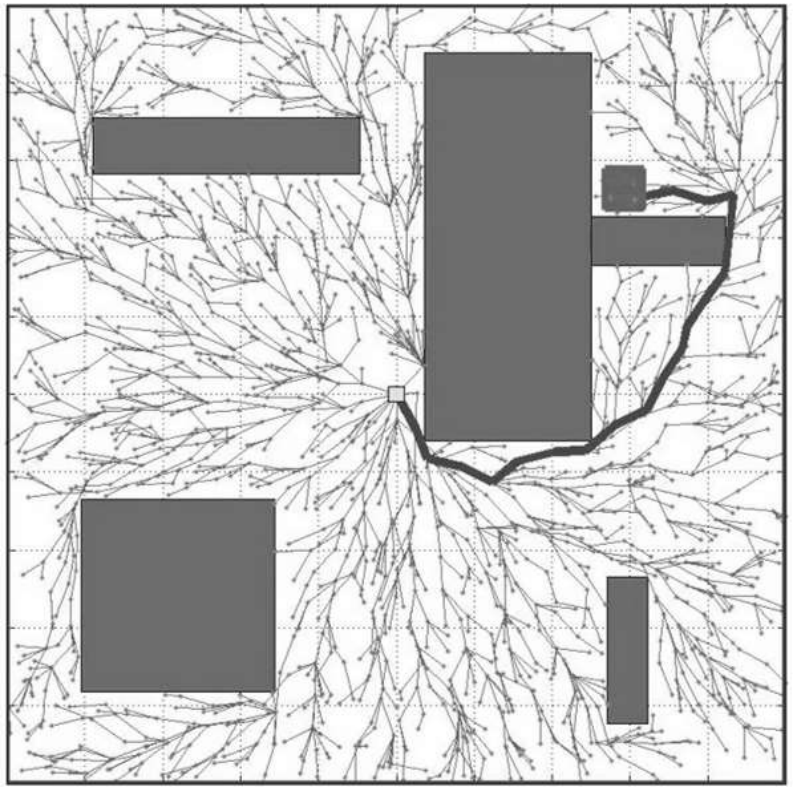
Sampling-based Approximation Algorithms for Reachability Analysis with Provable Guarantees

Lucas Liebenwein*, Cenk Baykal*, Igor Gilitschenski, Sertac Karaman, Daniela Rus
Distributed Robotics Lab, CSAIL, MIT

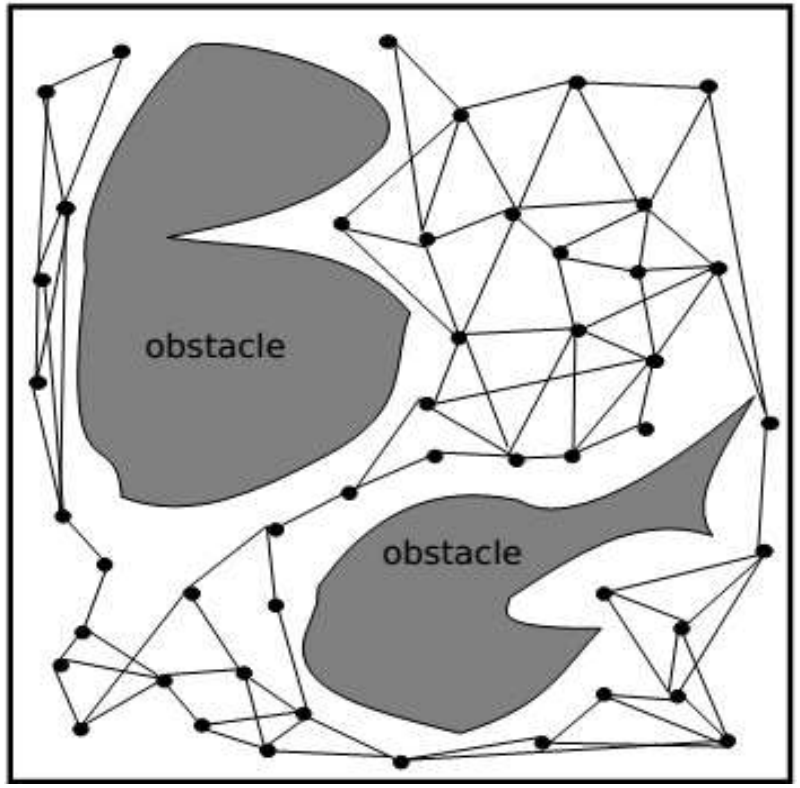
* Both authors contributed equally

Massachusetts Institute of Technology

Motion Planning – What We Wish For



Karaman, Sertac, et al. "Sampling-based algorithms for optimal motion planning." IJRR 2011.



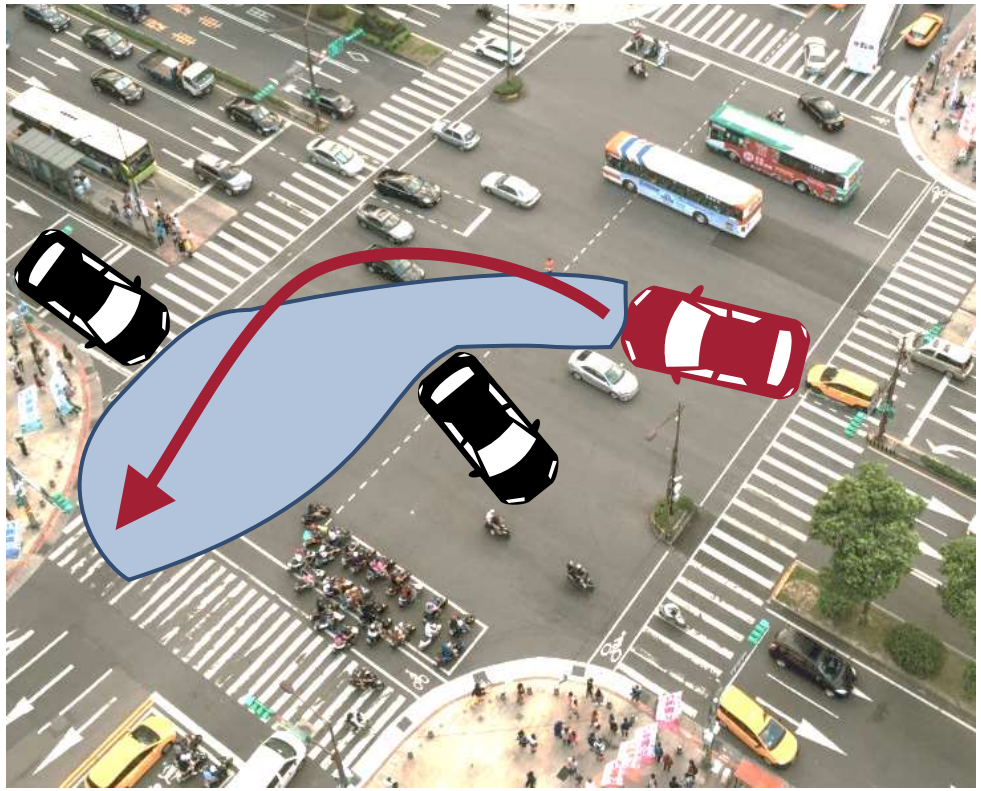
Murray, Sean, et al. "Robot Motion Planning on a Chip." *RSS*. 2016.

Motion Planning – What We Have

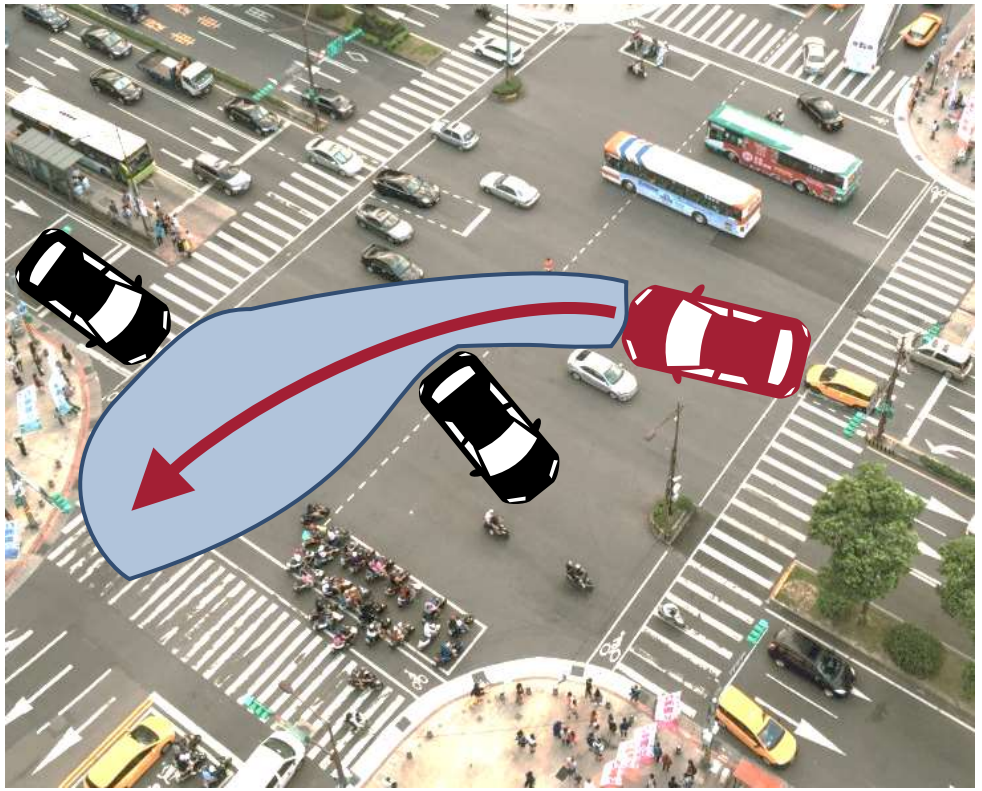
The New Nation, 06/28/2015

http://www.squirrel-project.eu/objectives.html

Reachability Analysis for Online Verification



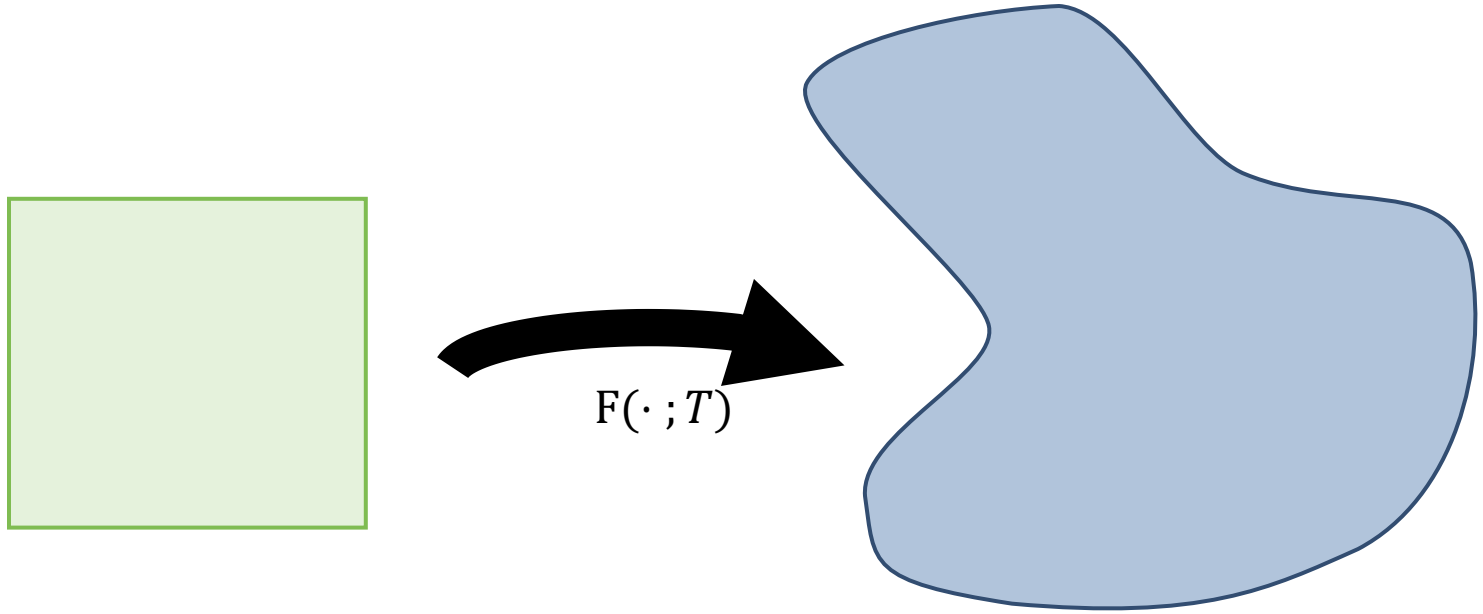
Infeasible Plan



Feasible Plan

Objective

For given timestep T, initial set $\mathcal{X}$, dynamics $h(x, u)$
find reachable set $F(\mathcal{X}; T)$



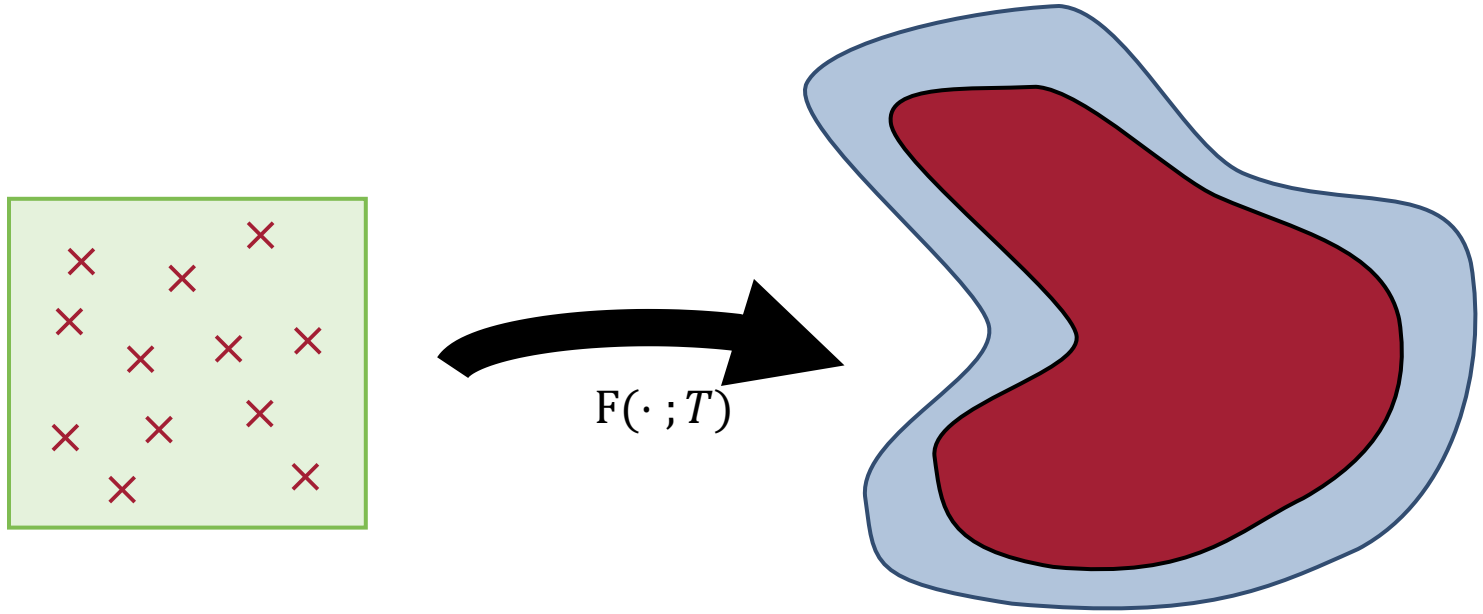
Initial set $\mathcal{X}$

Reachable set $\mathrm{F}(\mathcal{X}; T)$

Objective

For a reachable set $F(\mathcal{X};T)$, generate a subset $\mathcal{S} \subset \mathcal{X}$ such that

$$(1-\varepsilon)\mu\big(F(\mathcal{X};T)\big) \leq \mu\big(F(S;T)\big) \leq \mu\big(F(\mathcal{X};T)\big)$$



Subset $\mathcal{S}$

Underapproximation $\mathrm{F}(\mathcal{S};T)$

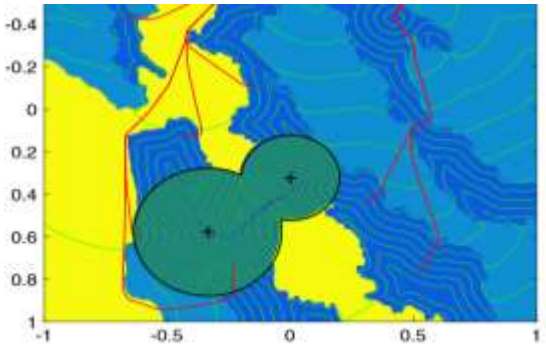
Main Challenge

Evaluating reachability involves reasoning about

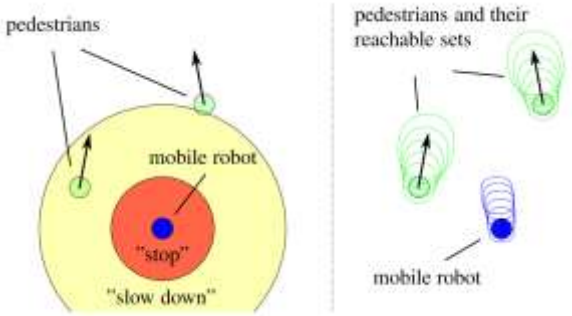
- Initial sets and how they evolve with respect to $F(\cdot; T)$
- State space and curse of dimensionality
- Trade-off between computation time and accuracy

In general, reachable sets cannot be evaluated (exactly) within a feasible amount of time

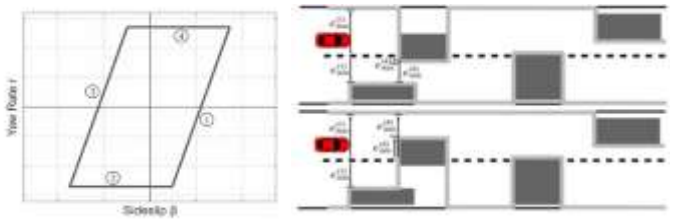
Related Work



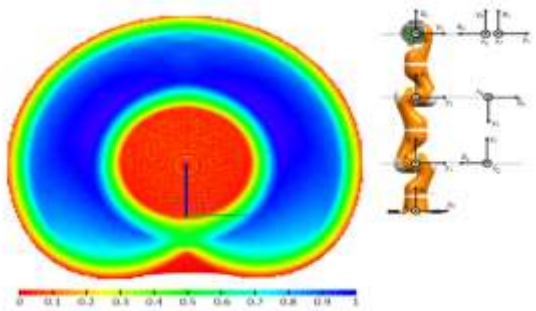
Chen, M., et al. (2017)



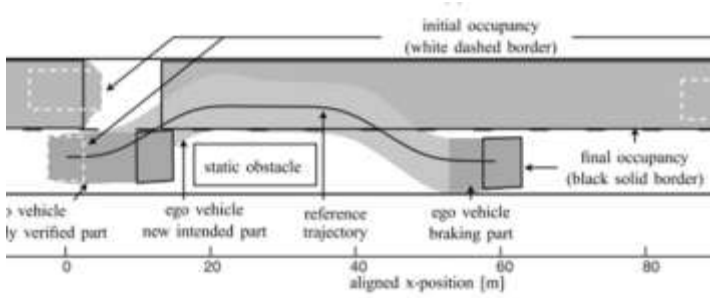
Liu, S.B., et al. (2017)



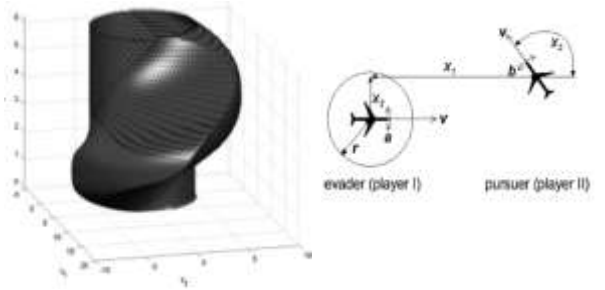
Erlien, S.M., et al. (2016)



Porges, O., et al. (2015)

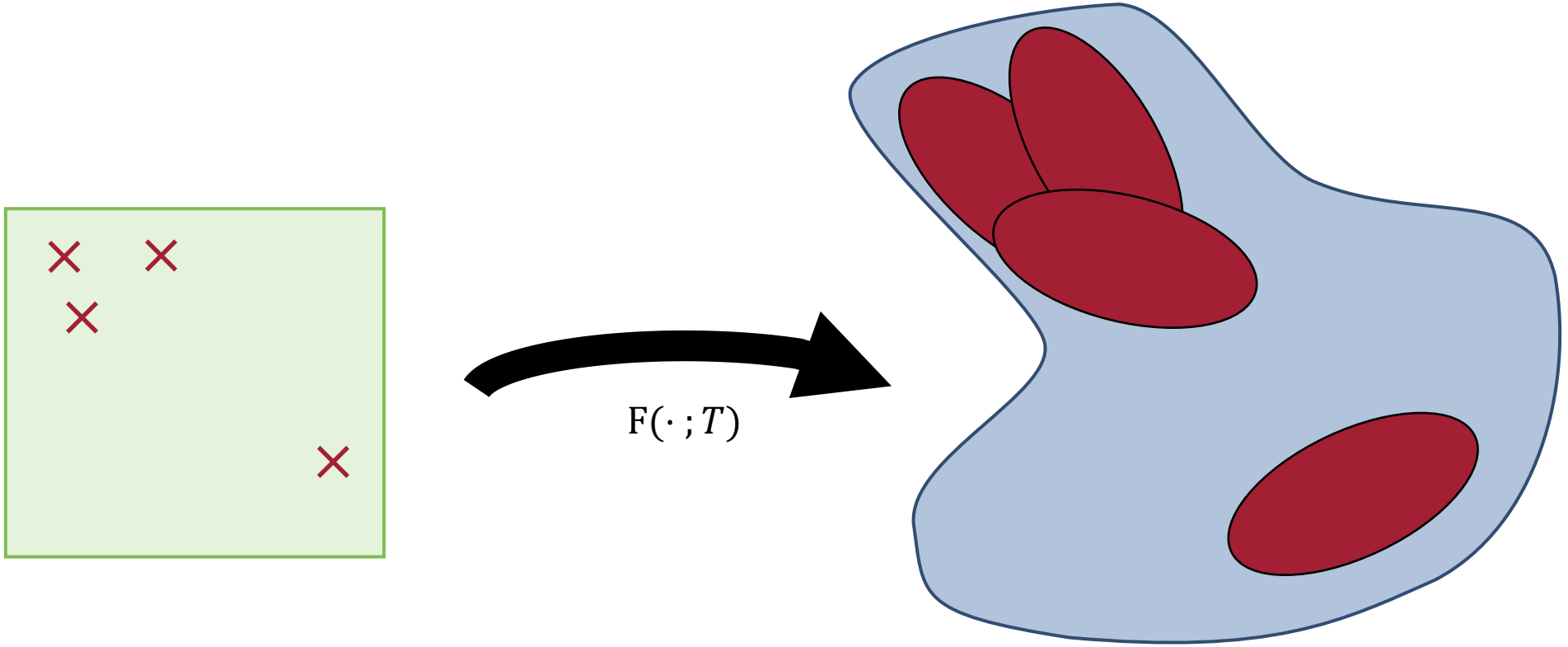


Althoff, M., et al. (2014)



Mitchell, I.M., et al. (2005)

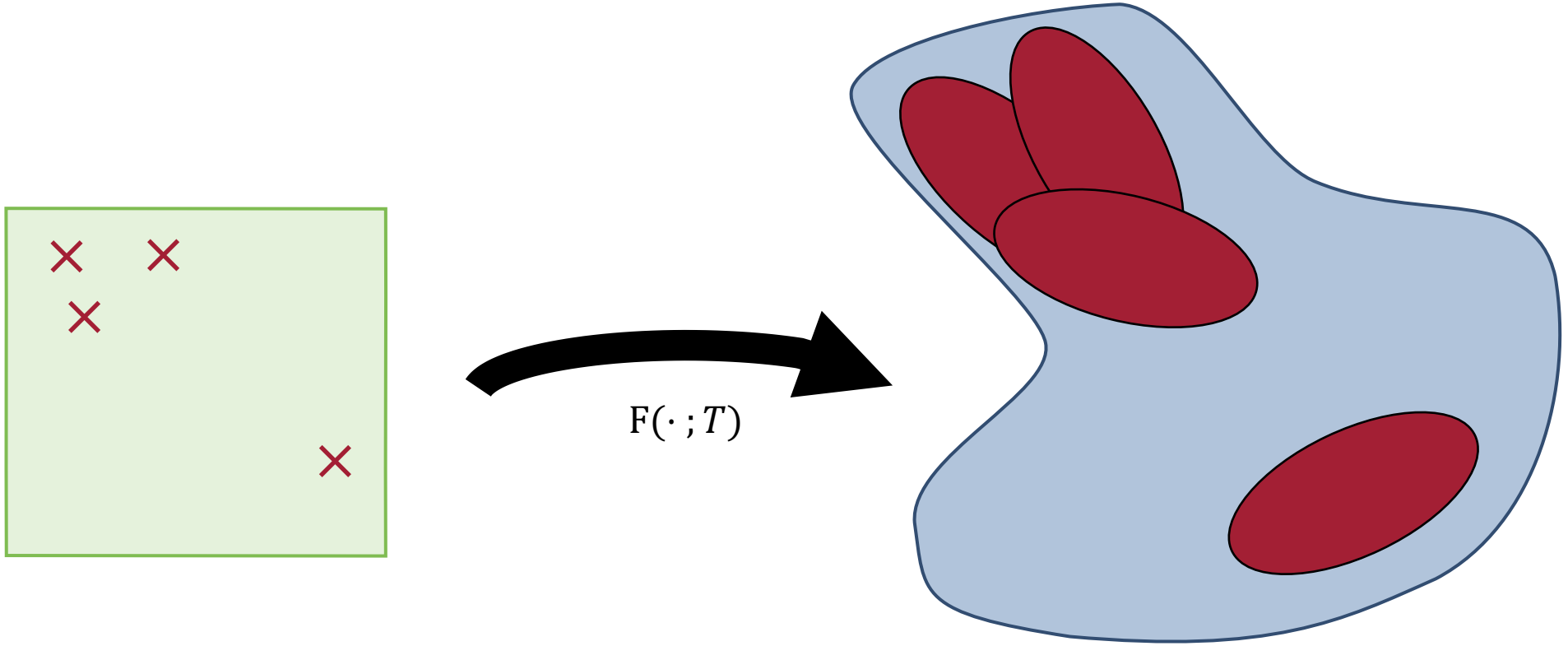
Method



Initial set $\mathcal{X}$

Reachable set $\mathrm{F}(\mathcal{X};T)$

Method



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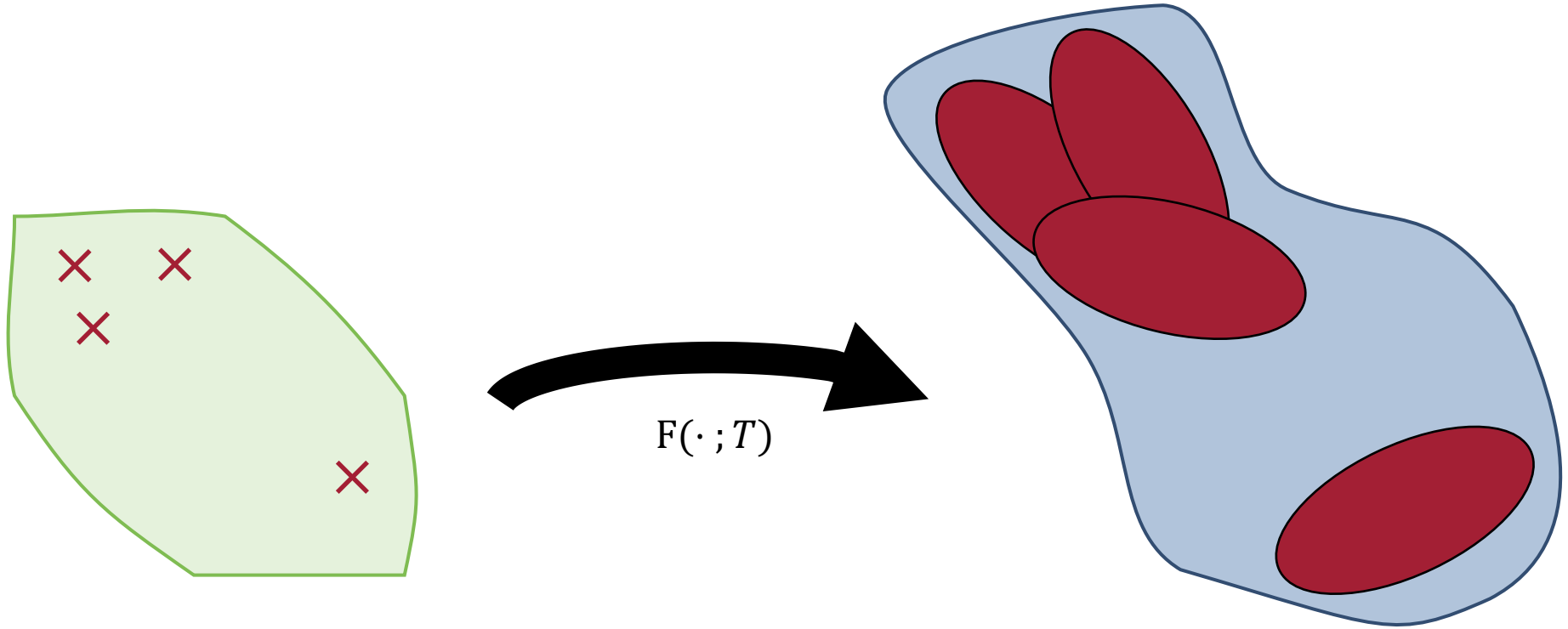

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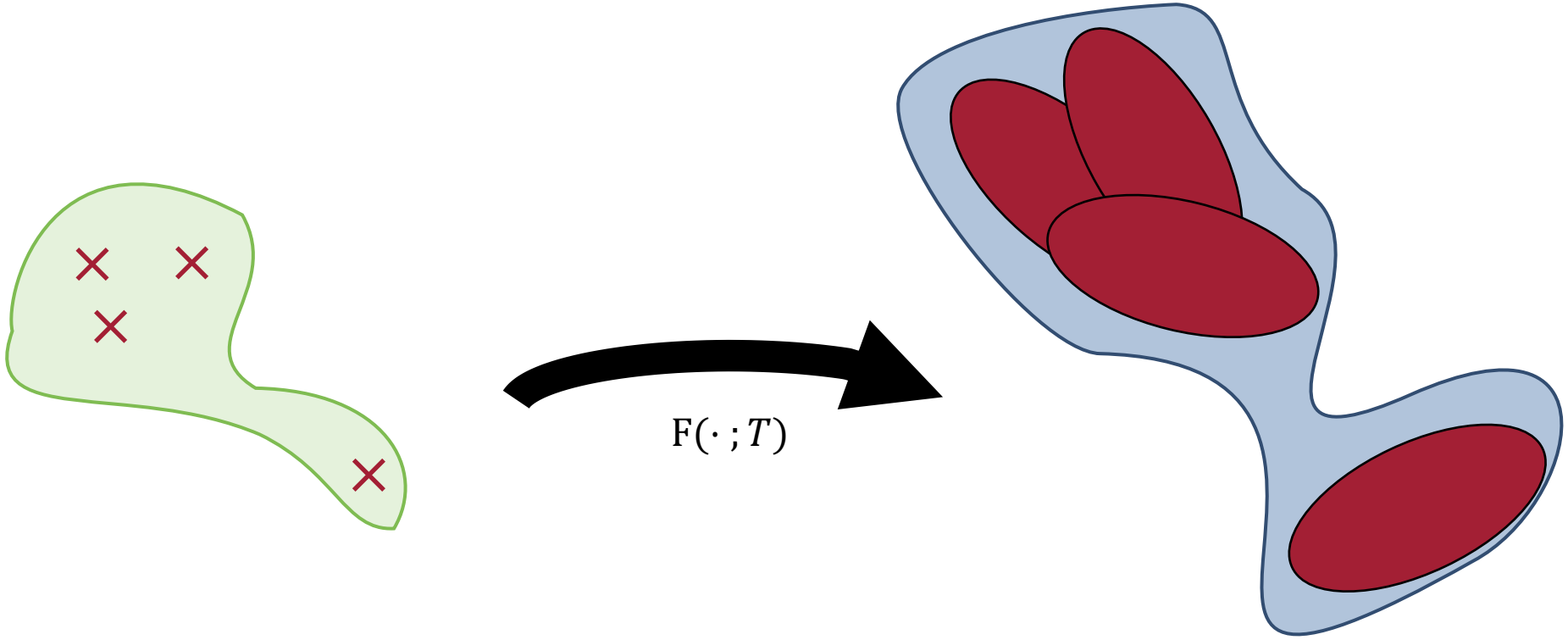

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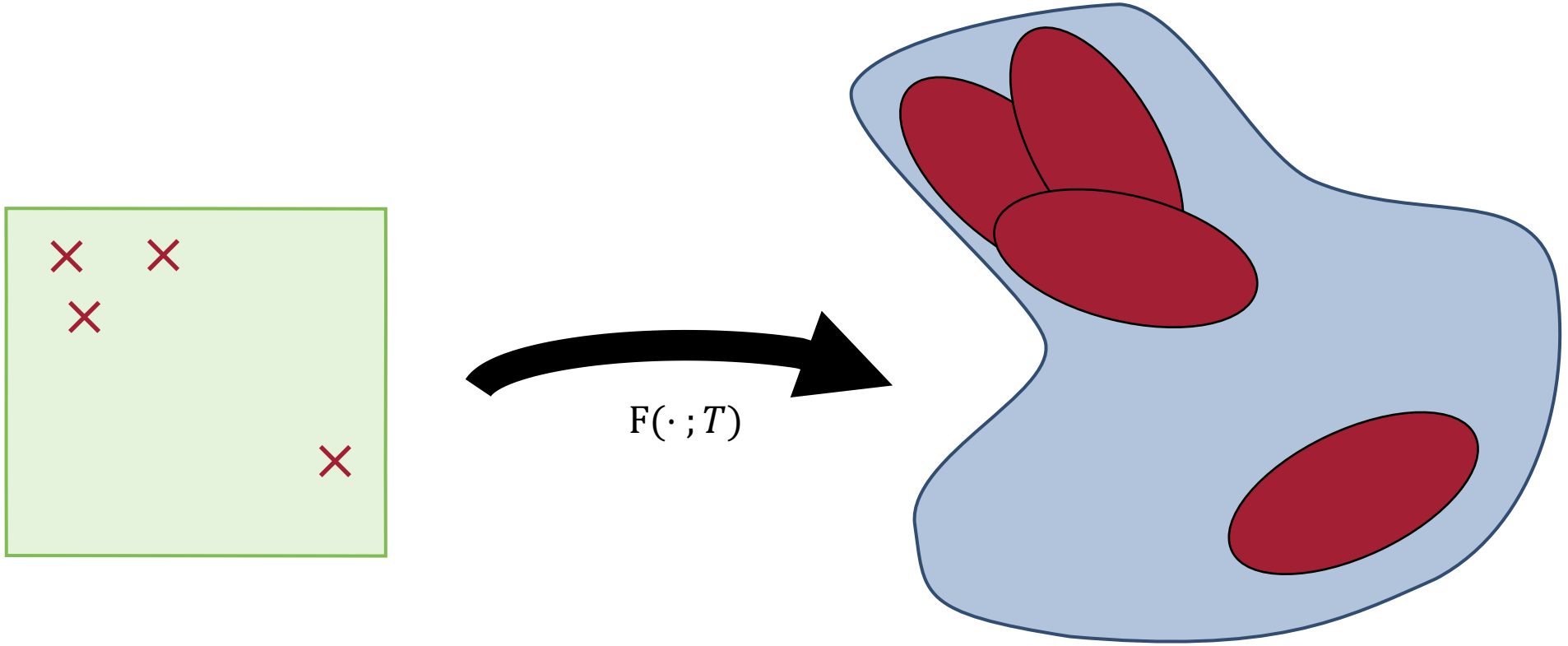

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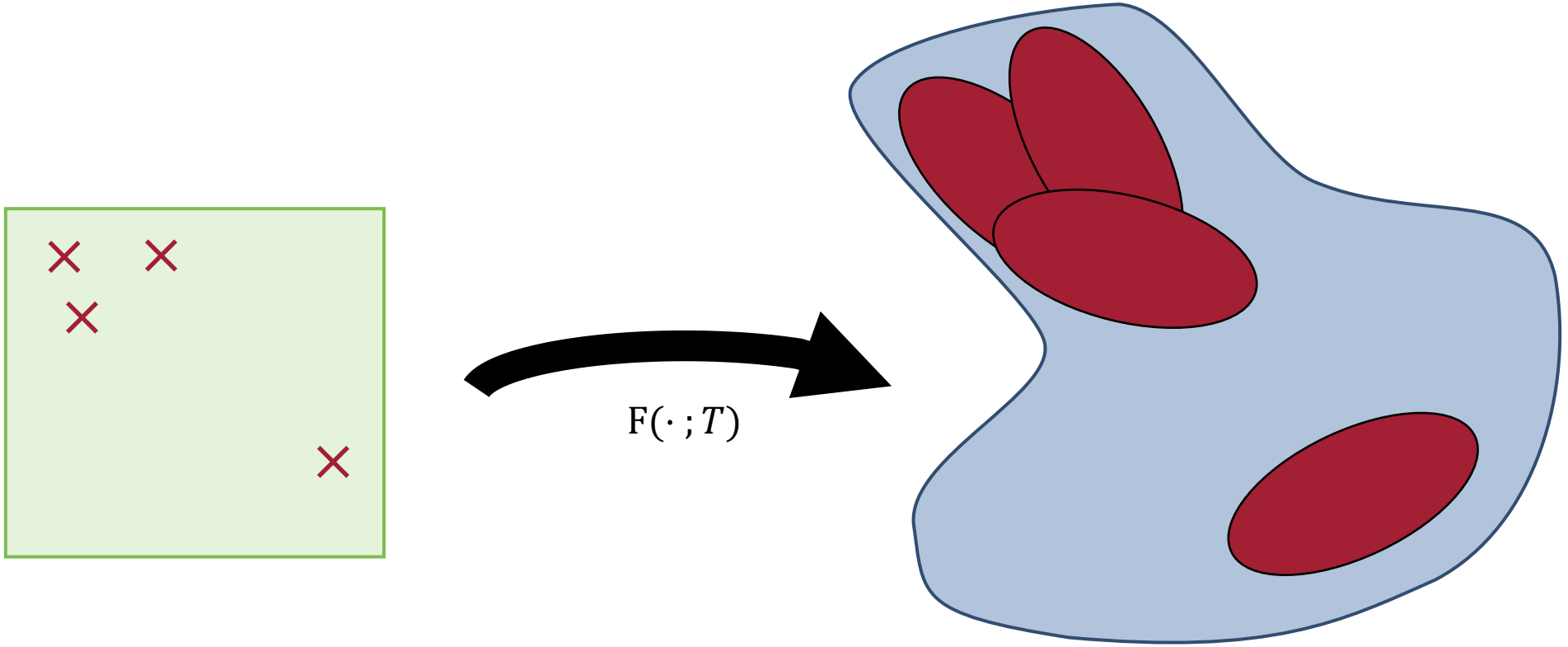
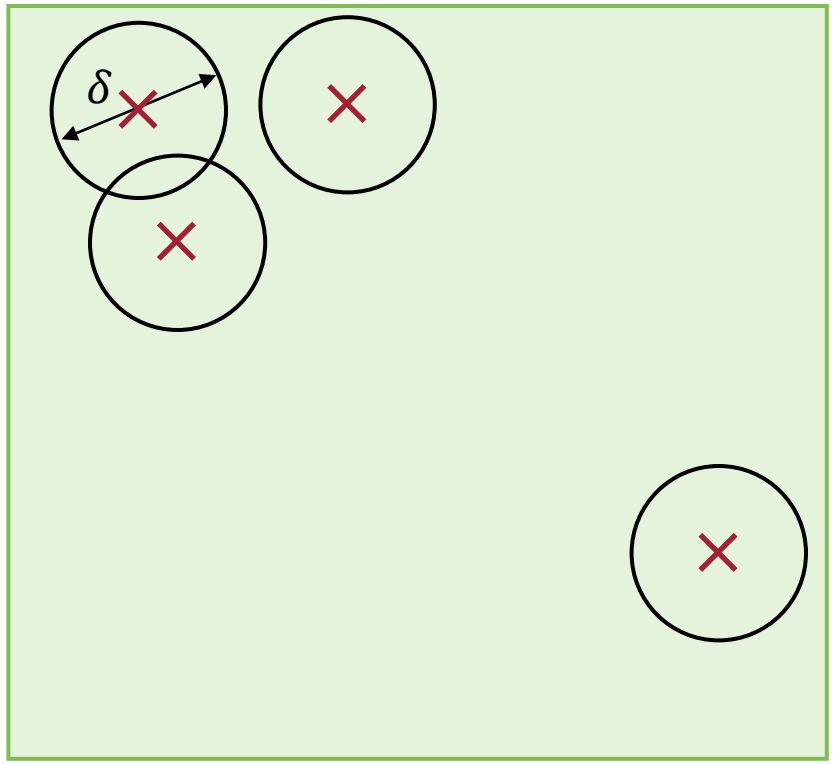


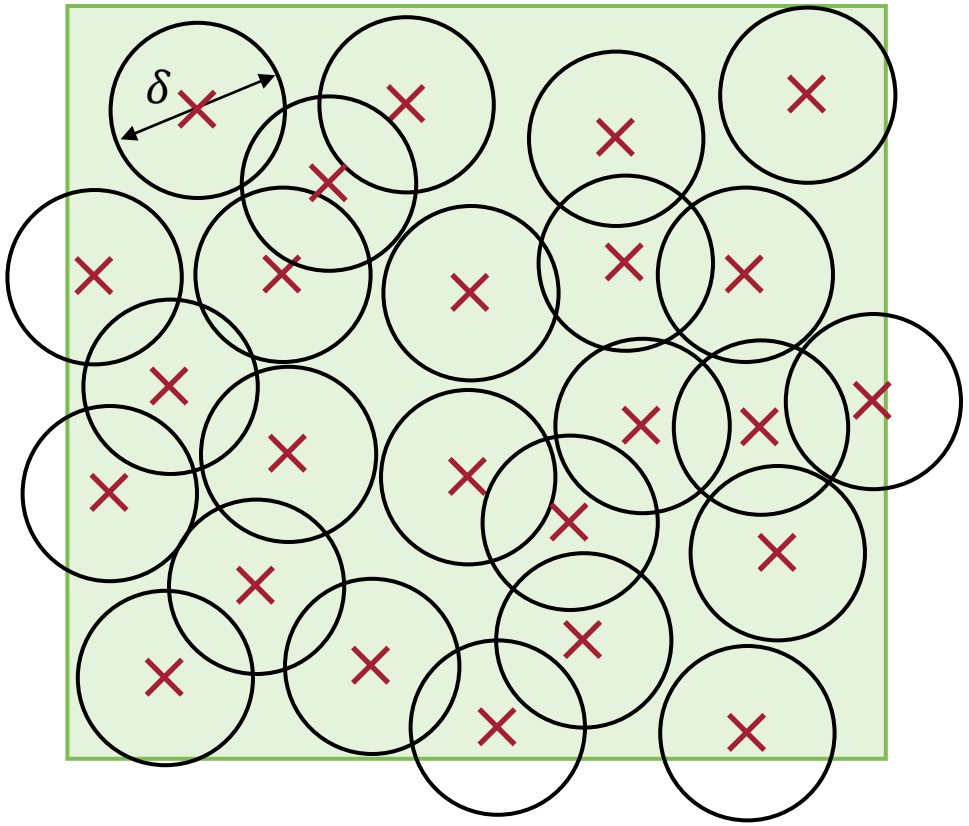
Initial set $\mathcal{X}$

Reachable set $\mathrm{F}(\mathcal{X};T)$

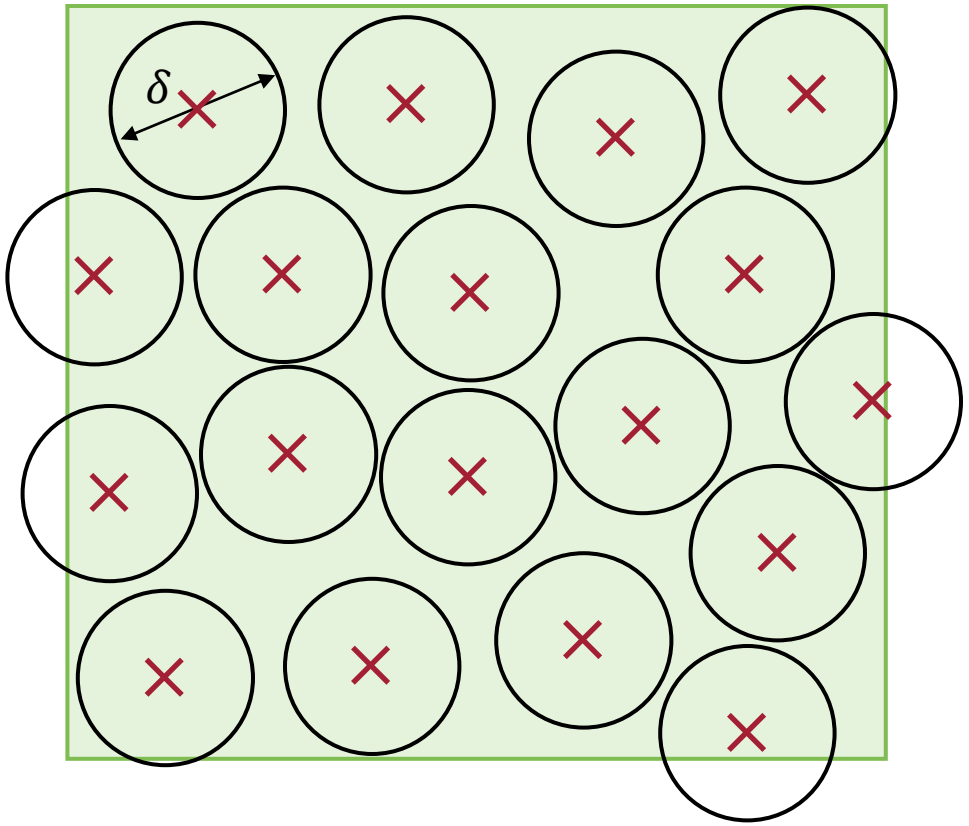
δ-Packing



δ-Packing

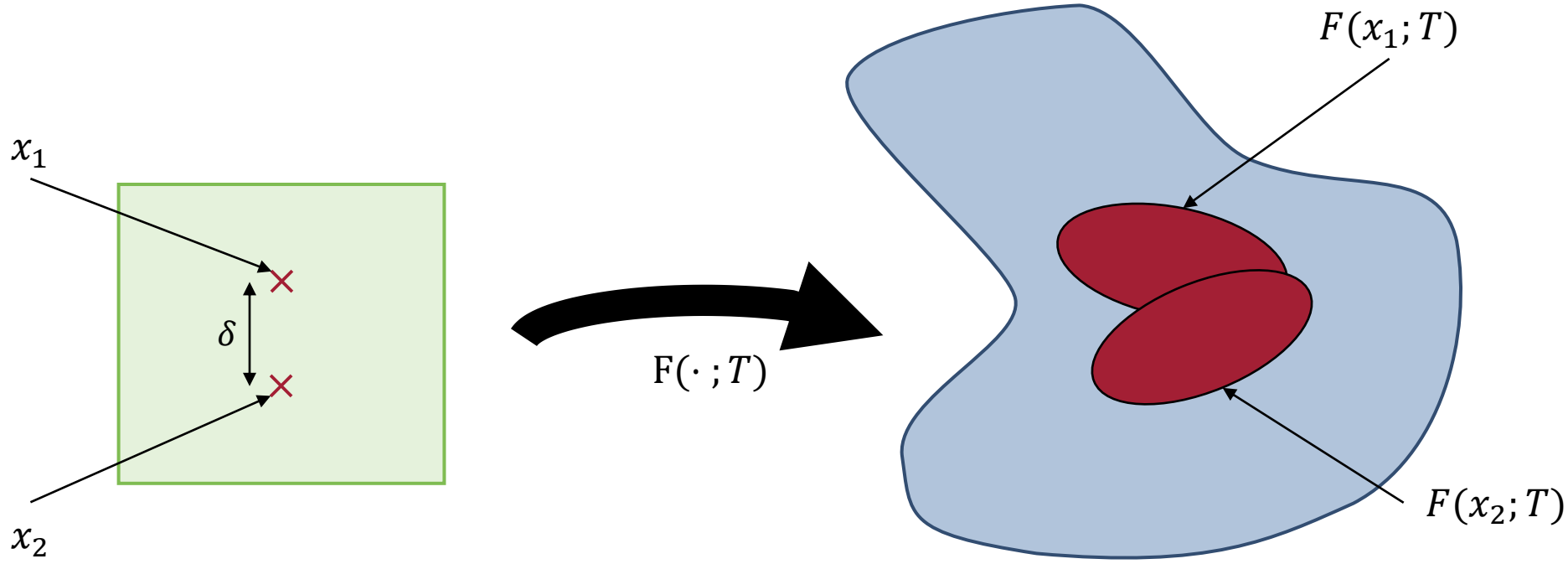


δ-Packing



δ-Packing

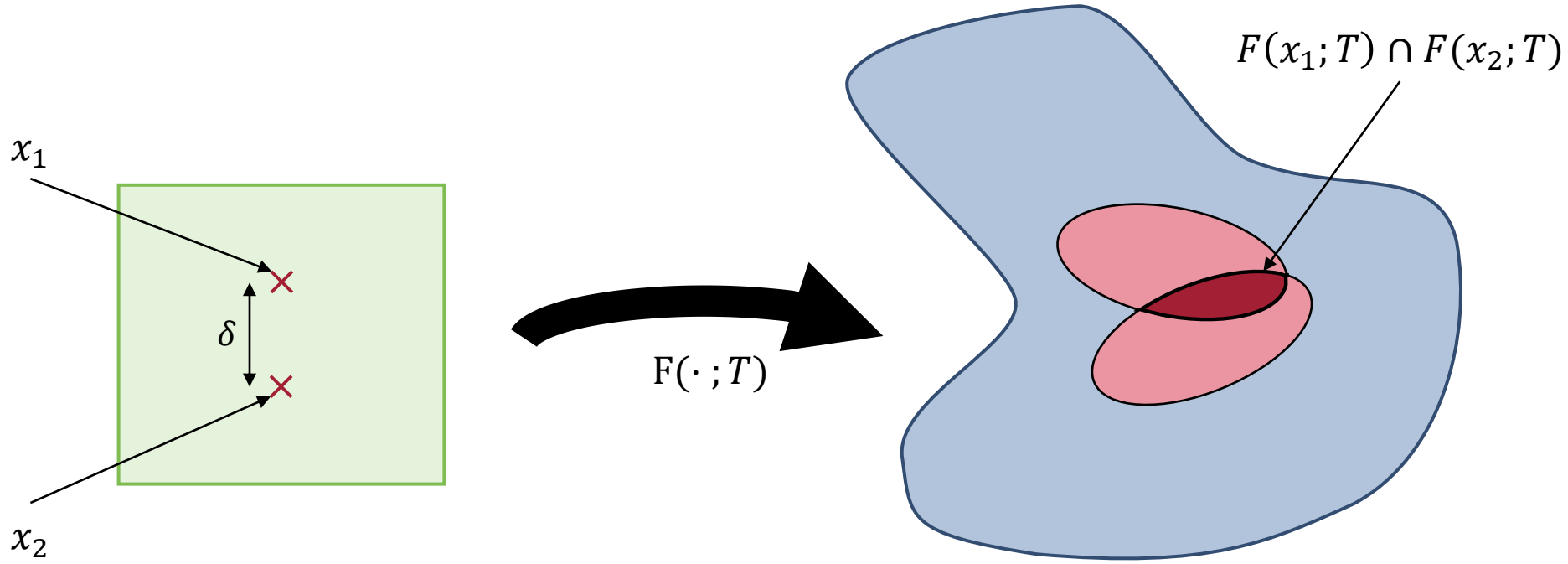
Reachable Set from δ-Packing



Initial set $\mathcal{X}$

Reachable set $\mathrm{F}(\mathcal{X}; T)$

Reachable Set from δ-Packing

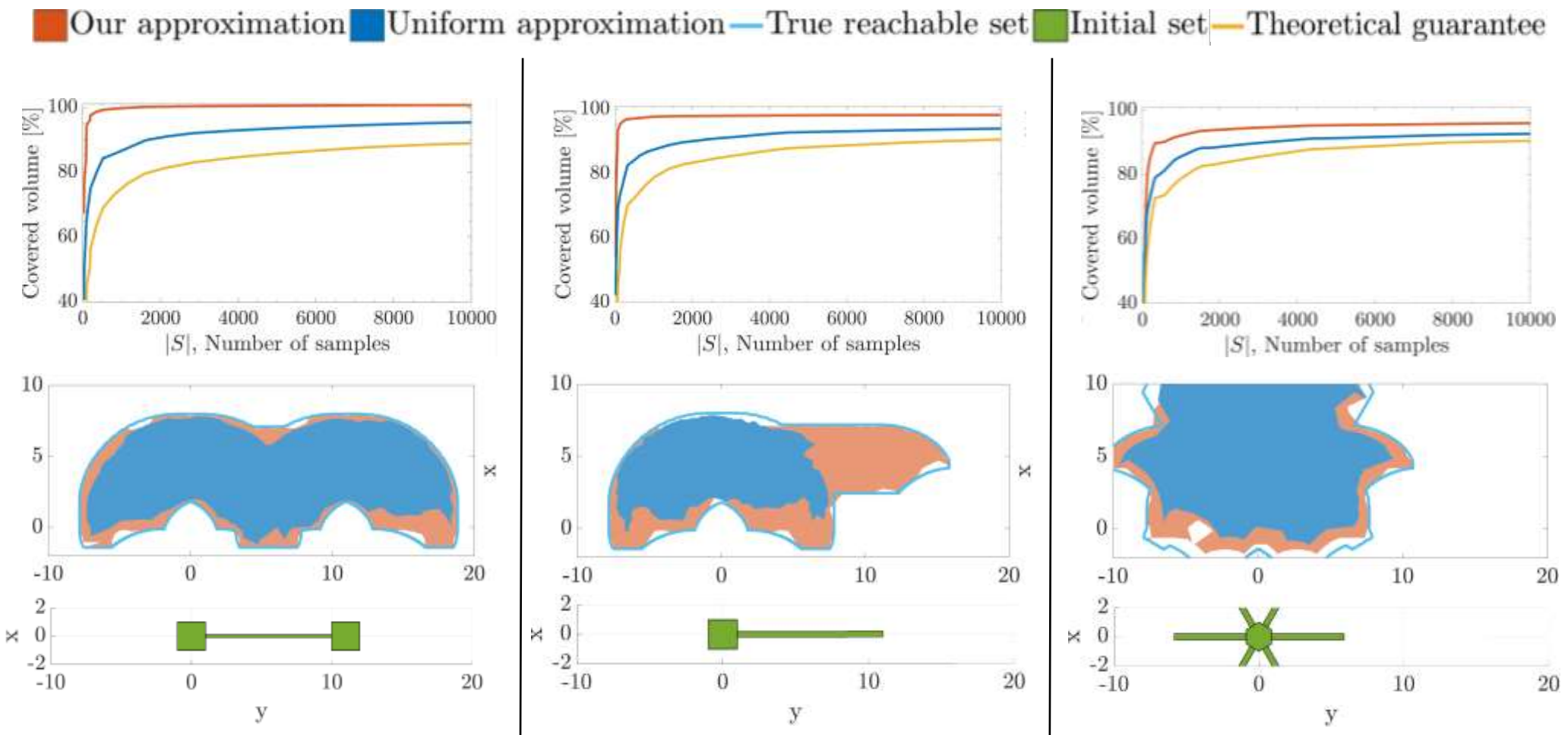


Initial set $\mathcal{X}$

Reachable set $\mathrm{F}(\mathcal{X}; T)$

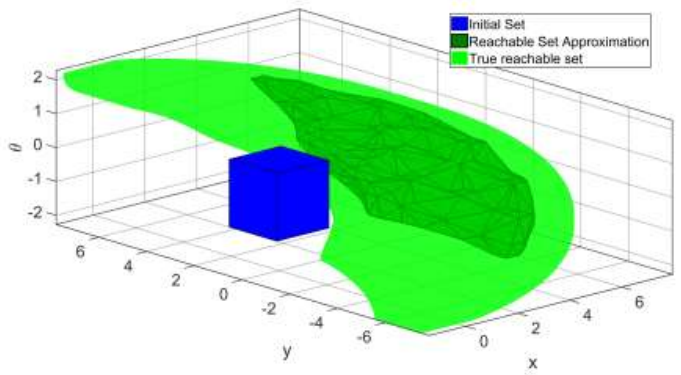
For a given δ-packing, there is an upper bound on volume of $F(x_1; T) \cap F(x_2; T)$ → Guaranteed underapproximation for user-specified ε (see paper for formal proof)

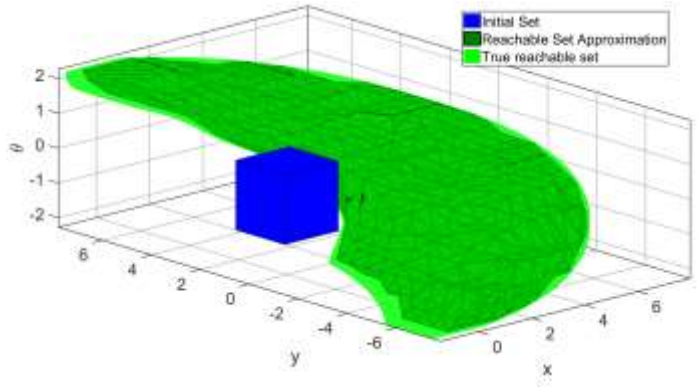
Results: Dubin's Car with Various Initial Sets



Dumbbell | Lollipop | Hedgehog

Thank you!





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