Sample-Based Methods for Factored Task and Motion Planning

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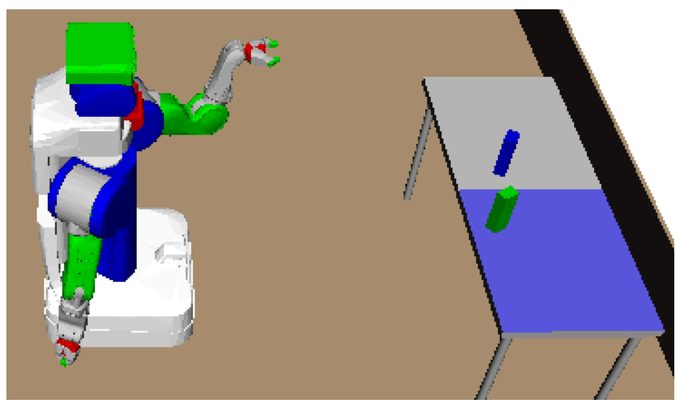
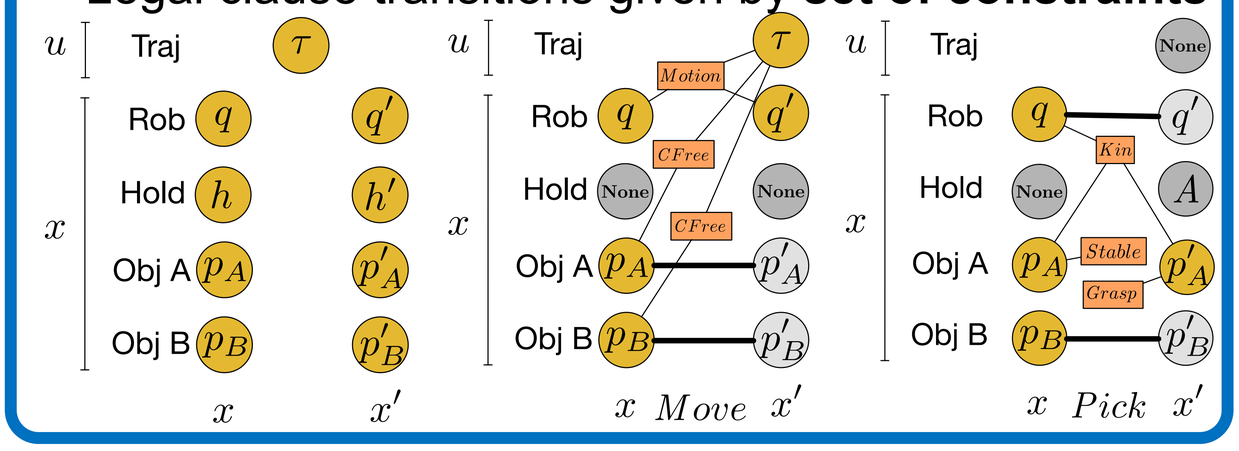
Task and Motion Planning (TAMP)

- **Robotic planning** with discrete & continuous values
  - **Discrete** - holding, clean, cooked, etc…
  - **Continuous** - configs, poses, grasps, trajectories
- **Example**: movable objects **A** (in blue) and **B** (in green)
- **Goal**: object **A** in blue region & robot return to start
- **State variables** (**x**)
  - Robot config (**q**)
  - Pose A/B (**p**)
  - Holding (**h**)
- **Control variables** (**u**)
  - Trajectory (τ)



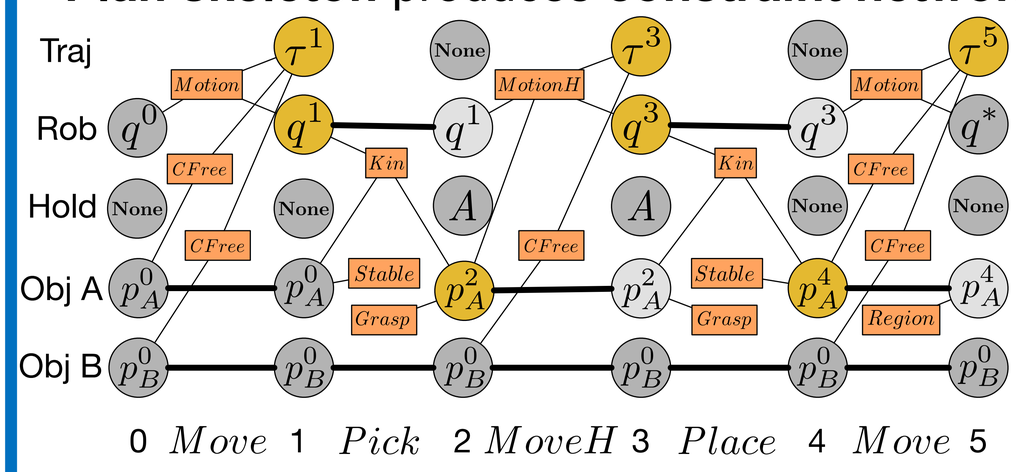
Factored Transition Systems

- TAMP **high-dimensional** but **factorable**
  - Can **sample** several variables at a time
  - Enables **efficient search** using **AI planners**
- Decompose **transition relation** into **clauses**
  - *Move, Pick* ***A/B,*** *Place* ***A/B,*** *MoveH* ***A/B***
  - Legal clause transitions given by **set of constraints**

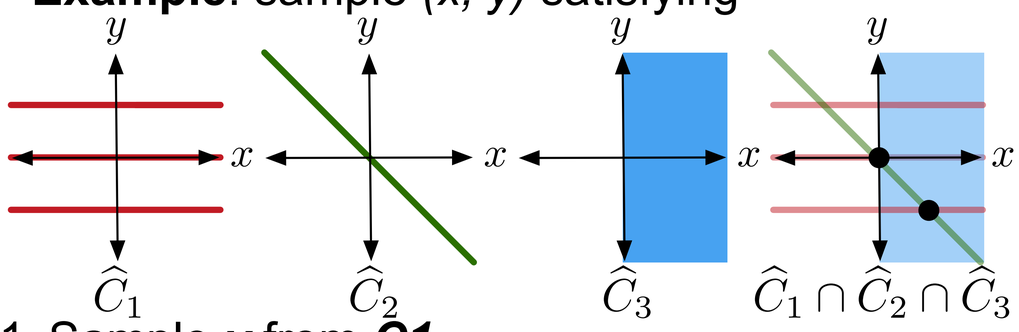


Low Dimensional Constraints

- **Plan skeleton** produces **constraint network**



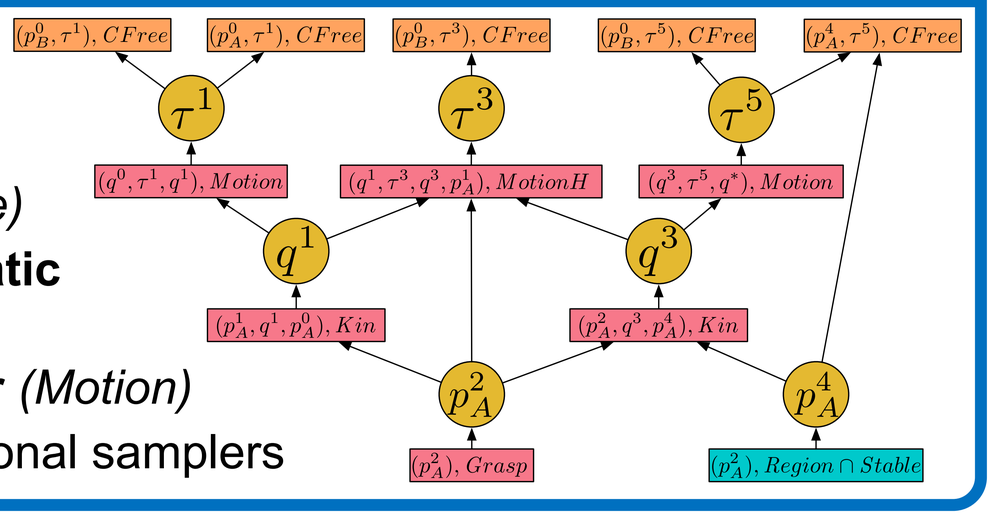
- *Motion, Kin, Stable, Grasp* **low dimensional**
  - How do we **sample their intersection?**
- **Example**: sample *(x, y)* satisfying



1. Sample ***y*** from ***C1***
2. Sample ***x*** from from ***C2*** conditioned on ***y***
3. Reject ***(x, y)*** violating ***C2***

Conditional Samplers

- Function from inputs to sampler
  - **Placement sampler** (*Stable)*
  - **Inverse kinematic solver** *(Kin)*
  - **Motion planner** *(Motion)*
- Compose conditional samplers

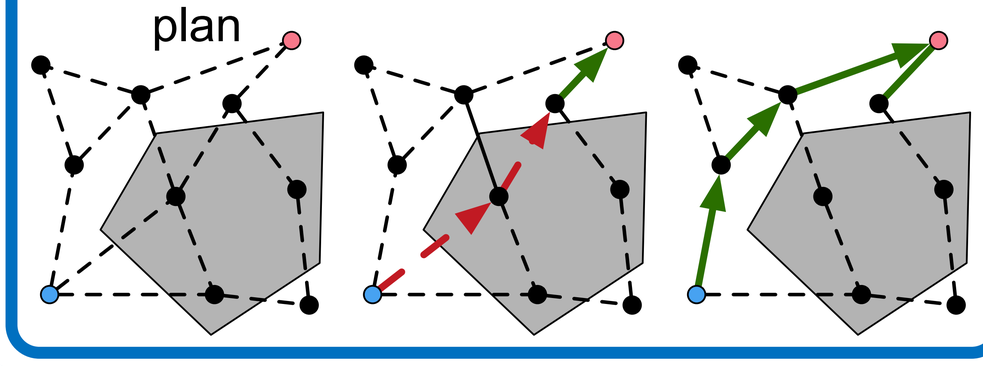


2 Domain-Independent Algorithms

- **Meta-parameter**: set of conditional samplers
  - **Probabilistically complete** given sufficient samplers
- **Incremental Algorithm** ≈ Probabilistic Roadmap (PRM)
  - Repeat:
    1. **Compose** and **sample** conditional samplers
    2. **Search** discretized problem for a plan
- **Off-the-shelf AI planning algorithms** for discrete search
  - Exploit factoring in their heuristics (e.g. FastDownward)

Focused Algorithm

- **Lazy** version of Incremental ≈ Lazy PRM
  - Optimistically assume can get samples
  - Repeat:
    1. Create **lazy** (placeholder) samples
    2. **Search** sampled problem composed of **real & lazy samples** for a plan
    3. **Sample** values for lazy samples on plan



Experiments

- **Code + STRIPS version -** https://github.com/caelan/stripstream