Variable Level-Of-Detail Motion Planning in Environments with Poorly Predictable Bodies

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Planning – “thinking/modeling the future”

- Given:
  - State space **X**
  - Initial state $\mathbf{x}_{init} \in \mathbf{X}$
  - Set of goal states $\mathbf{X}_{goal} \subset \mathbf{X}$
  - Set of actions **A**
  - A state transition **MODEL: resulting state x’** of **applying an action a ∈ A to a state x** *(a “model” because, at planning time, the action is not actually applied in the state and its effects are not actually observed)*
- Planning is the search for a sequence of actions $\mathbf{a}_1,\ldots,\mathbf{a}_n$ leading from $\mathbf{x}_{init}$ to a goal state $\mathbf{x}_{goal} \in \mathbf{X}_{goal}$

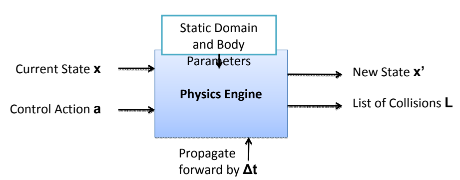
Physics-Based Planning

- Motion planning using domain models that reflect Newtonian physics as encountered in the real world

Stefan Zickler, PhD thesis, May 2010, CMU
www.szickler.net

Physics-Based State Transitions

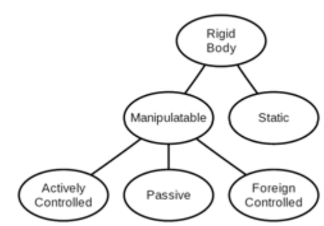
- How do we apply an action and simulate from one state to the next? Use a **Physics Engine**!



Physics-Based Model

- How do we model the physical world?
  - Rigid body dynamics
  - An approximation of real-world physics

Body Types



States

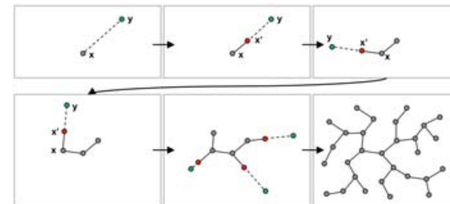
- The system's state **x** contains the state of all rigid bodies at a given point in time **t**:
  x= ⟨**t**, $\mathbf{r}_1$, … , $\mathbf{r}_n$⟩
- A single rigid body's state: $\mathbf{r}_i$= ⟨**p**,**q**,**v**,**w**⟩
  - **p**: position (3D vector)
  - **q**: orientation (3x3 rotation matrix)
  - **v**: linear velocity (3D vector)
  - **w**: angular velocity (3D vector)
- Other body parameters:
  - Shape, mass, material constants, …
  - Constant, thus not considered part of state-space

Actions

- An action **a** is a vector of sub-actions:
  a = ⟨ $\hat{a}_1$, …, $\hat{a}_n$ ⟩
- Each sub-action $\hat{a}_i$ is a ⟨ force, torque ⟩ pair applicable to a corresponding rigid body $\mathbf{r}_i$

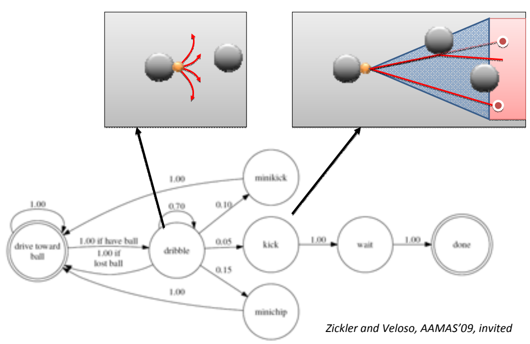
Planning Algorithm: Rapidly-Exploring Random Trees (RRT)

- Create a random sample **y** from some subspace **Y** of **X**
- Find the nearest neighbor **x** in tree **T** using some distance metric
- Expand from **x** toward **y**, creating a new child node y'



[S. LaValle, 1998] [J. Kuffner, S. LaValle, 2000]

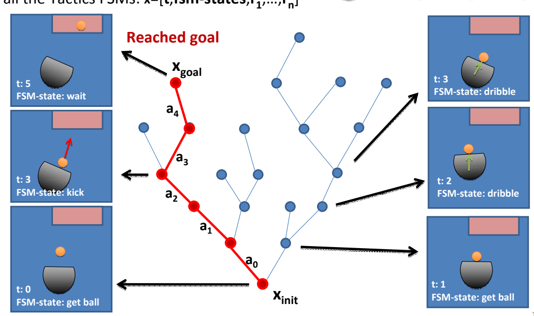
Physics-Based Planning with Non-Deterministic Skills and Tactics



Zickler and Veloso, AAMAS'09, invited

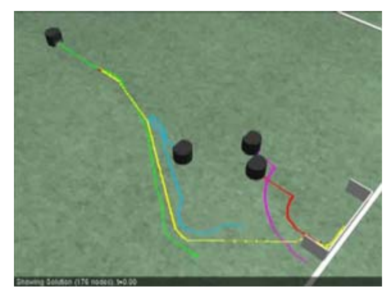
Physics-Based Planning Algorithm

Each node in the tree represents the complete physical state of the world and of all the Tactics FSMs: x=[**t**,**fsm-states**,$\mathbf{r}_1$,…,$\mathbf{r}_n$]



Physics-Based Planning

(still in simulation)



Stefan Zickler – PhD thesis 2010

Planning in a Dynamic World

- At each (re)planning iteration, the planner searches for a complete solution, trying to find a precise trajectory around moving objects , **all the way to the goal state.**
- In domains with high uncertainty, predictions for poorly modeled objects are likely incorrect.
- Generated plans fail early, and most of the plan will **never be successfully executed.**
- A waste of computational planning resources!

Key Question

- How can we make motion planning in environments with poorly predictable bodies more efficient?

Approach

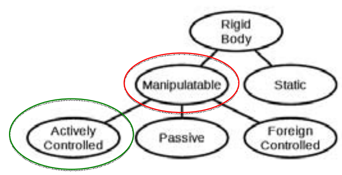
- ***Variable Level-of-Detail (VLOD)*** planning
- The planner should only worry about moving bodies:
  - preventing collisions in the *near future*
  - ignoring collisions in the *far future*

Variable Level-of-Detail (VLOD) Planning

- A method for relaxing the replanning problem by ignoring **details** that occur in the **future**
- **Future**: defined by time horizon threshold: $\mathbf{t_{LOD}}$
  - If $\mathbf{x.t > t_{LOD}}$ then ignore **details** during planning
  - Otherwise, plan with **full detail**

Variable Level-of-Detail Planning

- What is a **detail**?
  - Locally solvable multi-body interactions that do not affect the global topology of the plan if temporarily ignored
  - In our model: Interactions between the **actively controlled** and other **manipulatable** bodies



RRT-Based Planning Algorithm

```
T.AddVertex(x_init); //start with a tree that only contains our initial state
repeat until we give up
    y := SampleRandomState(Y); //generate a random sample from the sampling space Y
    x := NearestNeighbor(T,y); //find nearest neighbor to y in T
    a := Controller(x,y); //generate an action from x toward y
    SetupCollisionMatrix(x); //sets up the currently applicable level of detail
    [x', L] := SimulatePhysics(x, a); //apply and simulate the control action
    if isValidState(x', L) then //check if any constraints have been violated
        T.AddVertex(x'); //add x' as a child of x
        T.AddEdge(x, x', a); //saving the control action a as edge
        if x' is in X_goal then return x'; //have we reached the goal?
    end if
```

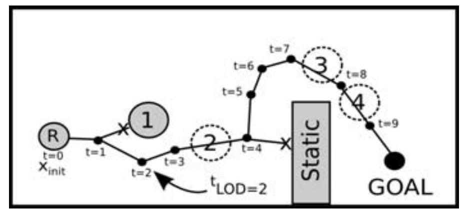
Reconfiguring the Collision Matrix **M**

```
Algorithm 5: SetupCollisionMatrix
// Let m_ij denote the element at the i-th
   row and j-th column of M.
for i ← 1 to n do
    for j ← i to n do
        if i=j then
            m_ij ← 0;
        else
            if (x.t > t_LOD and
            ((r_i ∈ B_Controlled and r_j ∈ B_Manip) or
            (r_j ∈ B_Controlled and r_i ∈ B_Manip))) then
                m_ij ← 0;
                m_ji ← 0;
            else
                m_ij ← 1;
                m_ji ← 1;
```

M is symmetric ($m_{ij}=m_{ji}$)
$m_{ij}=1$: collision between r_i and r_j should be simulated and reported in the list of collisions **L**
$m_{ij}=0$: collision between r_i and r_j should be ignored and not reported in **L**

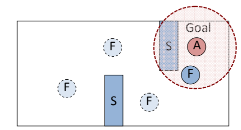
VLOD Example

- **t_{LOD}=2**



R: Controlled Robot Body
1-4: Foreign-Controlled or other Manipulatible Bodies

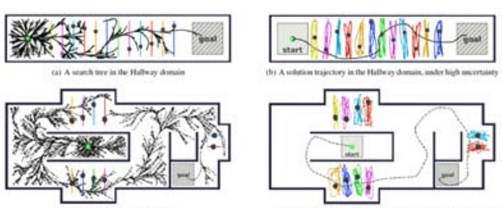
VLOD Example



A: Actively controlled body
F: Foreign controlled body
S: Static body

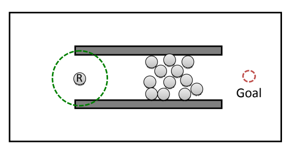
Experimental Domains

- Navigate through a field of rapidly moving foreign-controlled bodies
- Foreign-controlled bodies have simulated uncertainty
- Controllable replanning interval t_{replan}
- Controllable VLOD time horizon t_{LOD}



Assumptions / Limitations

- VLOD assumes that details are **locally solvable** (within t_{LOD}).
- Imagine the following scenario:



- Solution: increase t_{LOD} or redefine what constitutes a detail, depending on the particular domain

Conclusion

- VLOD planning can significantly increase planning speed without increasing number of collisions
- VLOD planning is applicable to many dynamic navigation domains