Amorphous Robotic Construction

Nils Napp

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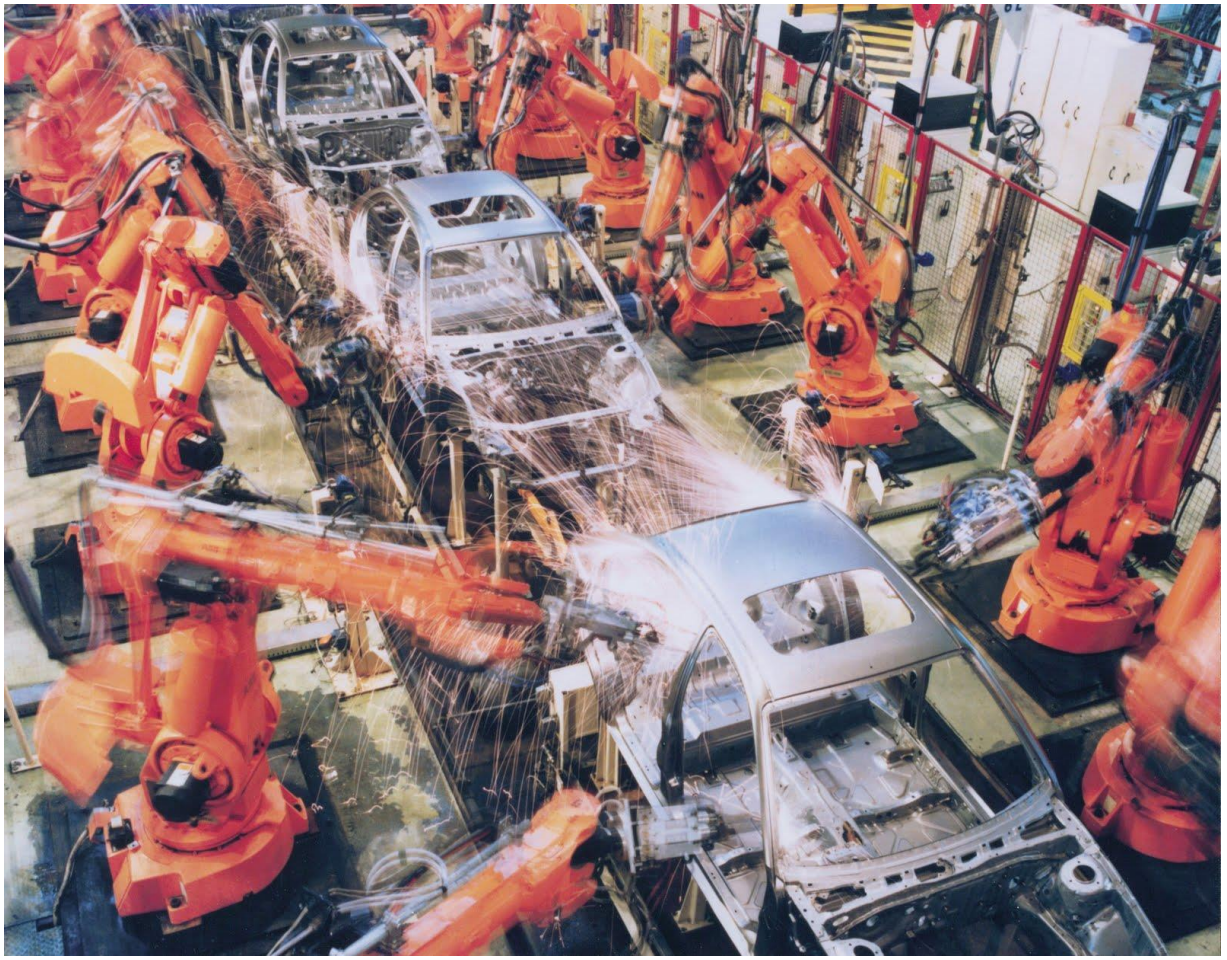
Robots Building Stuff



Robotic Construction in Messy Environments

Related Work

Petersen, Werfel, Nagpal 2011

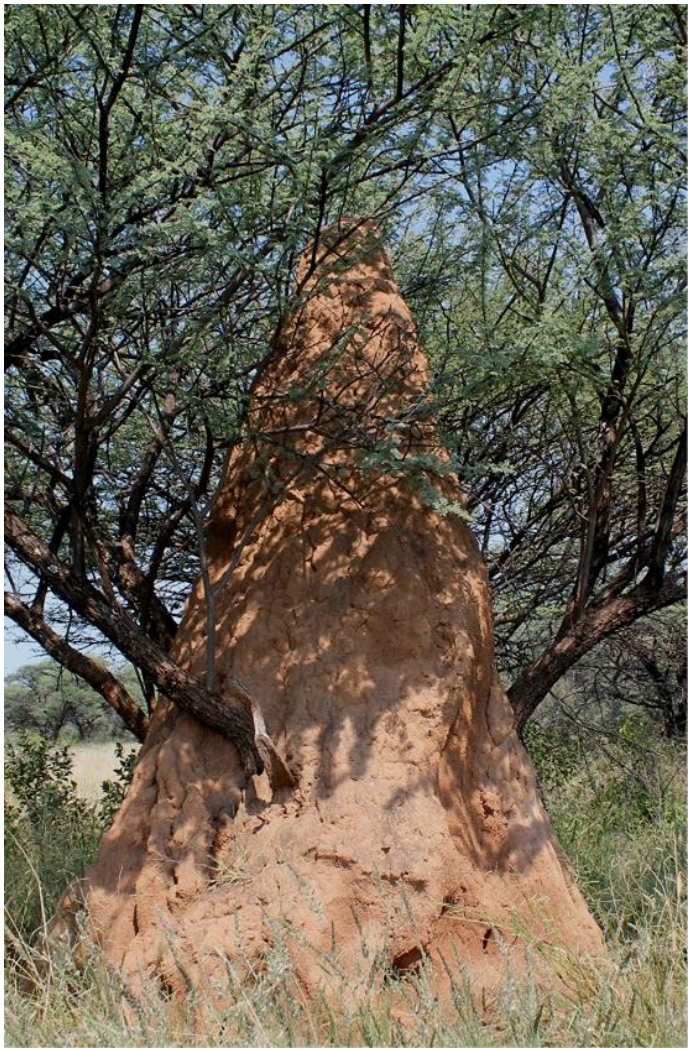
Khoshnevis 2004

Rus, Lipson, Yim

Lindsey, Mellinger, Kumar 2010

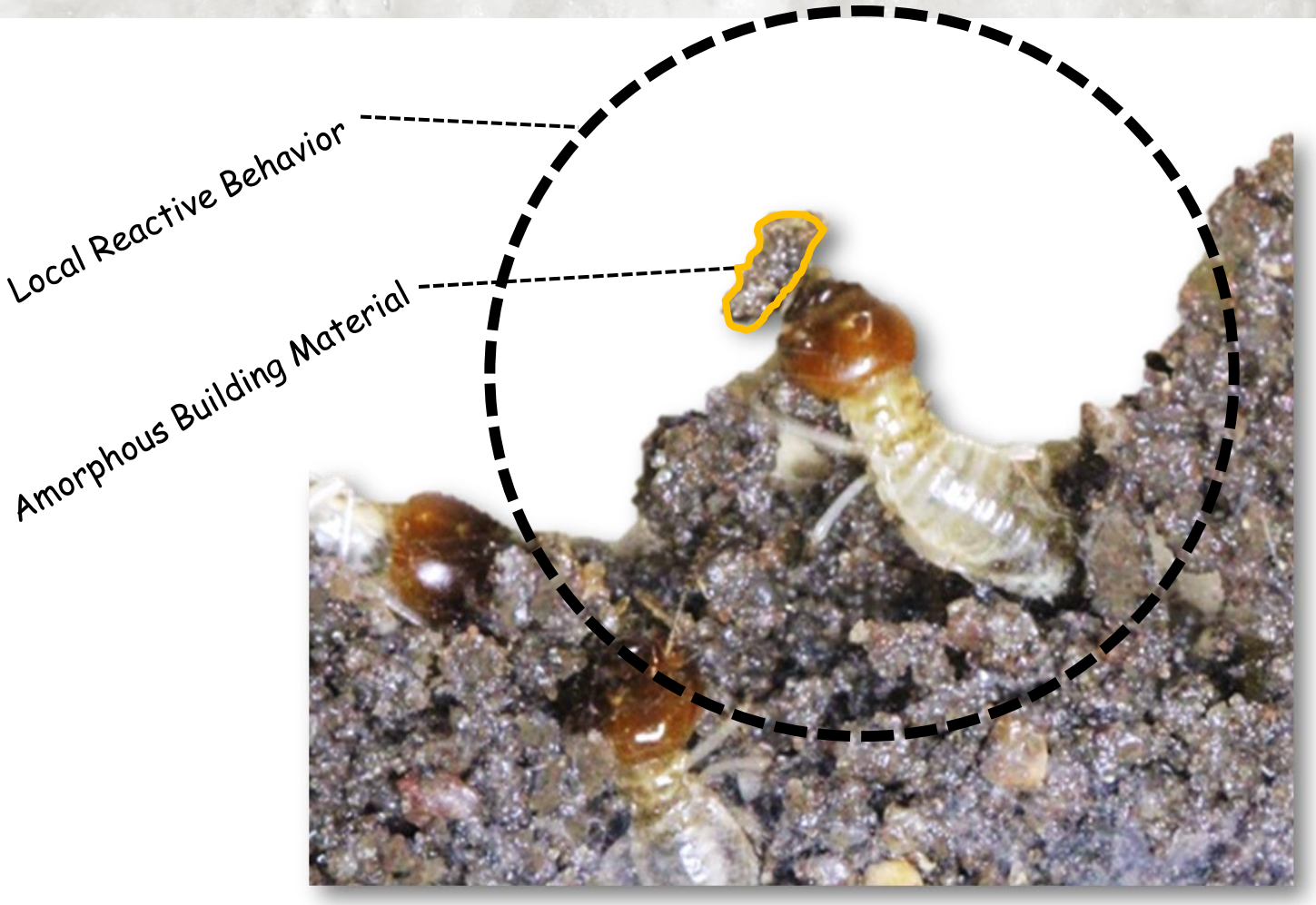
D'Andrea 2010

Biological Inspiration



K. Petersen**, N. Napp,** J. Chin-Lee, J. Werfel and R. Nagpal, 3D Tracking of Building Processes in Macrotermes , Visual Observation and Analysis of Animal and Insect Behavior, Workshop (ICPR), 2012.

Biological Inspiration



Outline

- Algorithm Design
  - Adaptive Ramp Building Problem 
  - World and Material Model
  - Navigable Structures
  - Ramp Building Algorithm(s)
- Experiments
  - Working in 3D
  - Deposition Experiments

Adaptive Ramp Building

Develop algorithms and robots to build in unstructured environments

N. Napp, J. M. Wu, O. R. Rappoli, and R. Nagpal, *Materials and Mechanisms for Amorphous Robotic Construction*. IROS 12

Algorithmic Challenges

1. Modeling Amorphous Depositions

2. Planning with Amorphous Depositions

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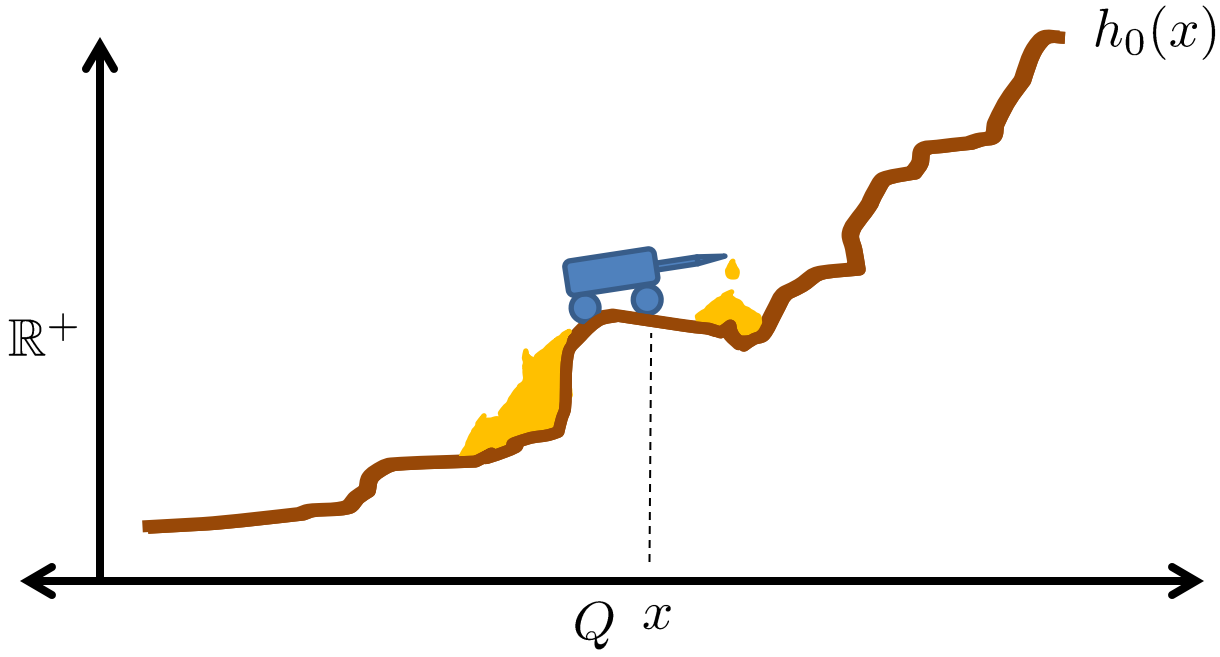
Modeling Structures

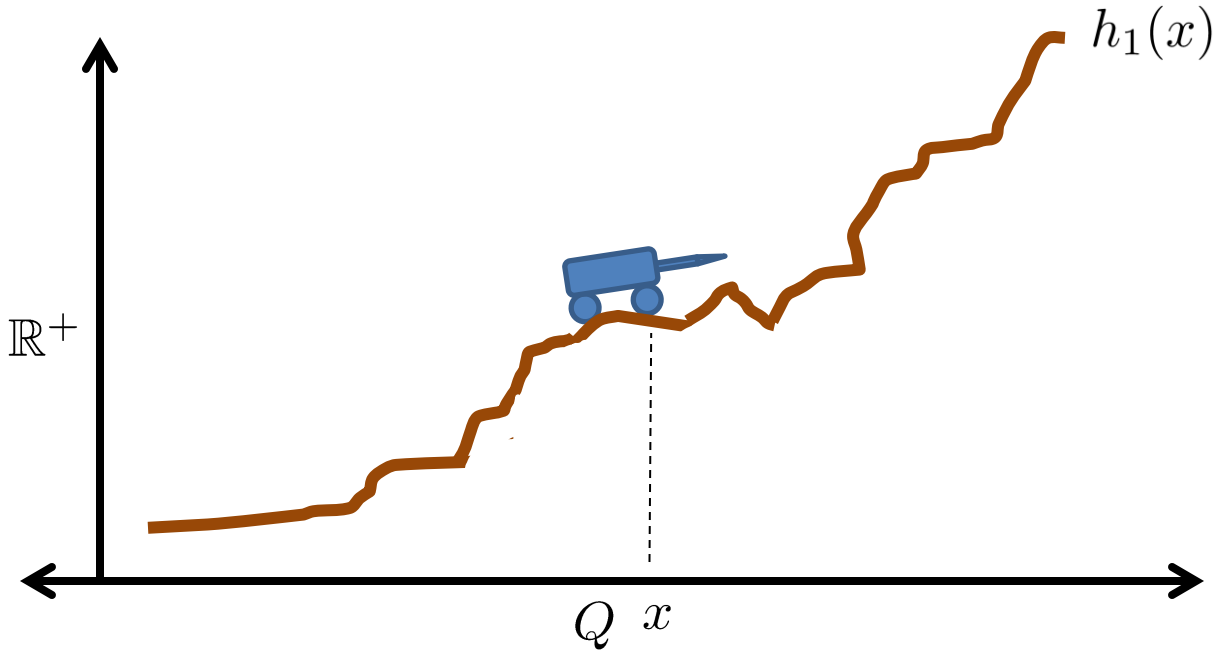


Q : finite building area

x : robot position

$h_n(x)$: height function

Modeling Structures



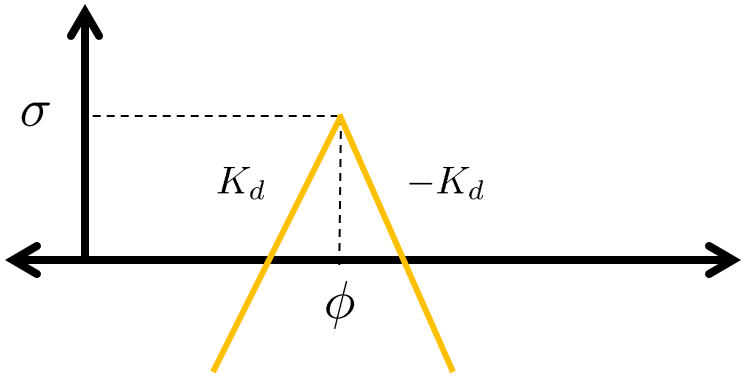
Q : finite building area

x : robot position

$h_n(x)$: height function

Modeling Amorphous Depositions

- Shape defined by the environment
- Conforming on bottom
- Top defined by *shape function*: $f_{(\phi,\sigma)}(x)$



$$f_{(\phi,\sigma)}(x) = \sigma - K_d|x - \phi|$$

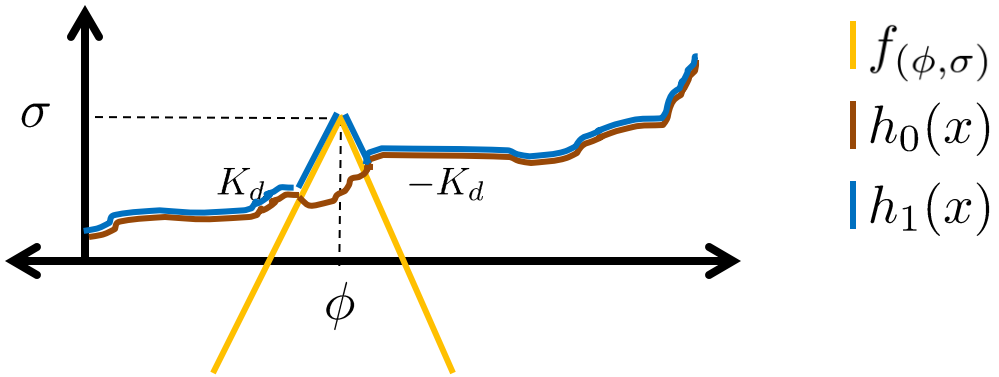
Modeling Amorphous Depositions

Deposition operator

INPUT: shape function and height function

OUTPUT: new height function

$$D[f_{(\phi,\sigma)}, h_n](x) = \max\{f_{(\phi,\sigma)}(x), h_n(x)\} = h_{n+1}(x)$$



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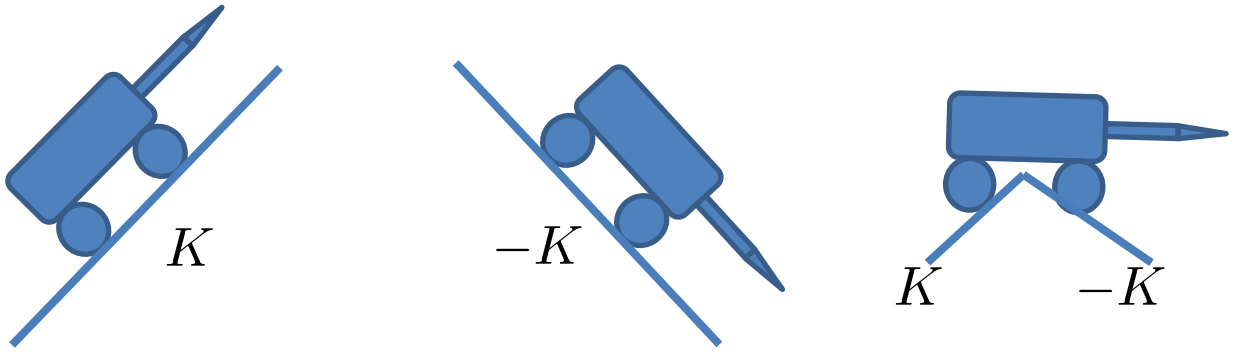
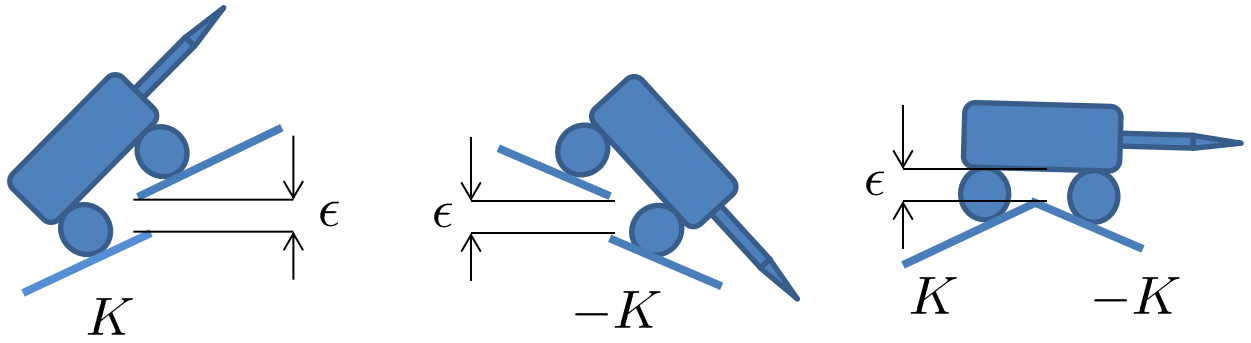
Maximum Climbable Steepness



A function $h(x)$ is called *K*-Lipschitz iff

$\forall x, y \in Q \quad |h(x) - h(y)| \leq K|x - y|.$

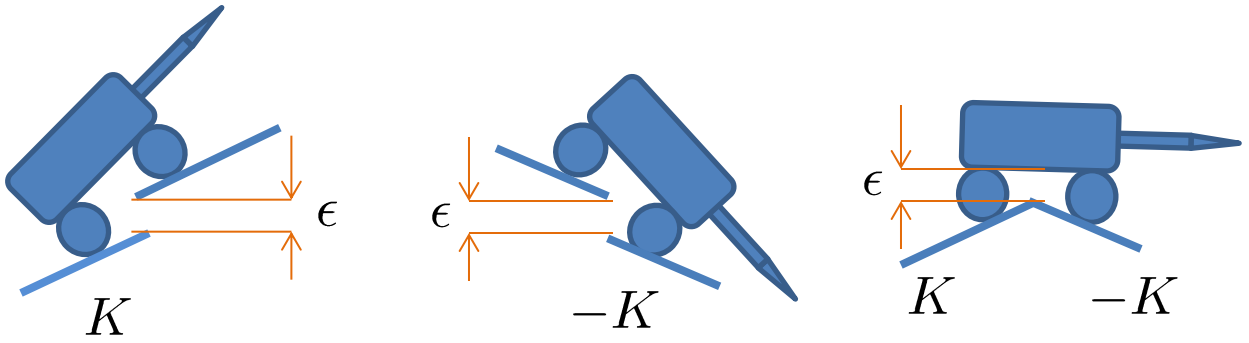
Navigable: Almost, Locally, Lipschitz



A function $h(x)$ is called *navigable* iff

$$\forall x, y \in Q \text{ with } |x - y| \leq r \quad |h(x) - h(y)| \leq K|x - y| + \epsilon.$$

Navigable: Almost, Locally, Lipschitz



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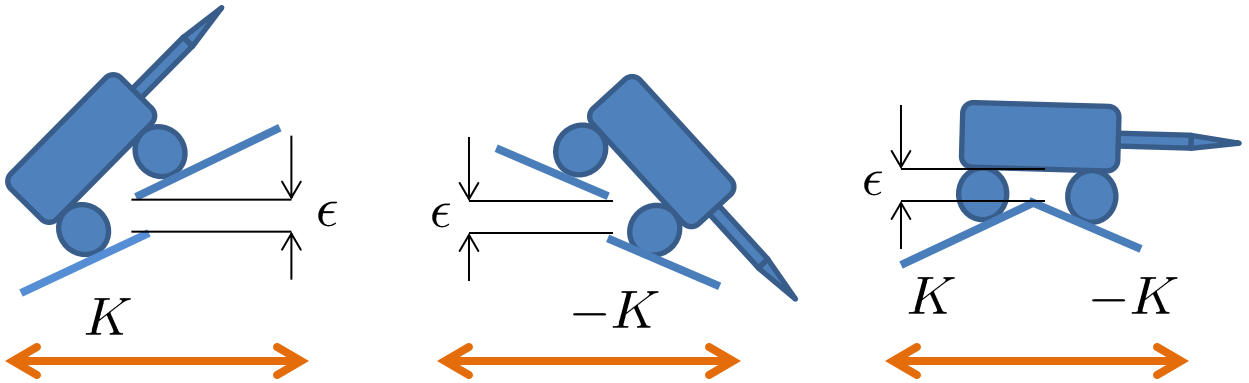

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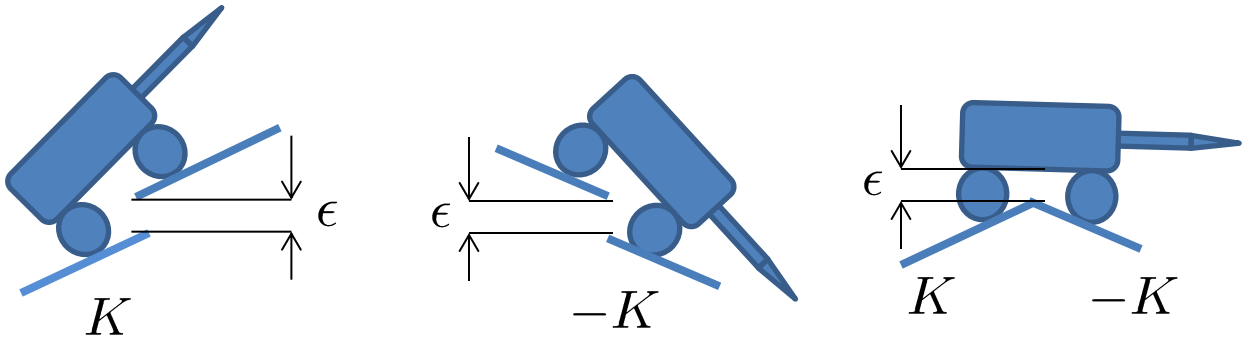

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Local Reactive Algorithm for Making *Navigable* Structures

Algorithm 1

1. Given $h_0 \in \mathcal{Q}^+$
2. Set $n = 0$
3. While $\exists\, y, y' \in Q$ s.t. $|y' - y| \leq r$ violating the navigability condition
4. Set ϕ to be point with lower h value (wlog assume $\phi = y'$)
5. Pick deposition height $\sigma \in [h_n(y') + \epsilon, h_n(y) - h_n(y') - K|y' - y|]$
6. Deposit at (ϕ, σ): $h_{n+1} = D[f_{(\phi,\sigma)}, h_n]$
7. Set $n = n + 1$
8. EndWhile

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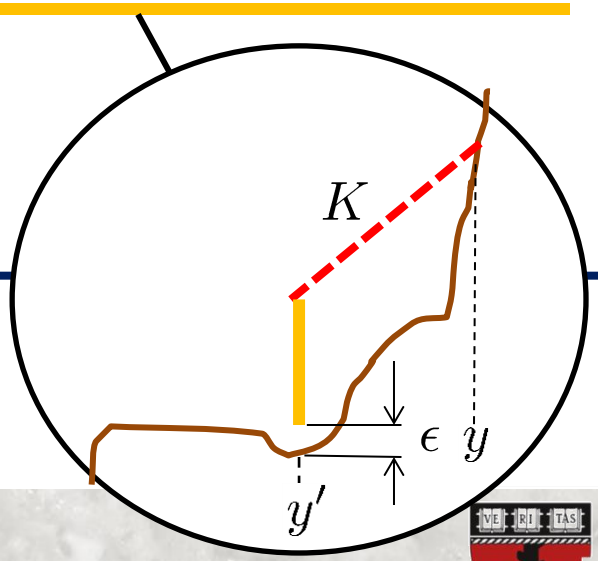
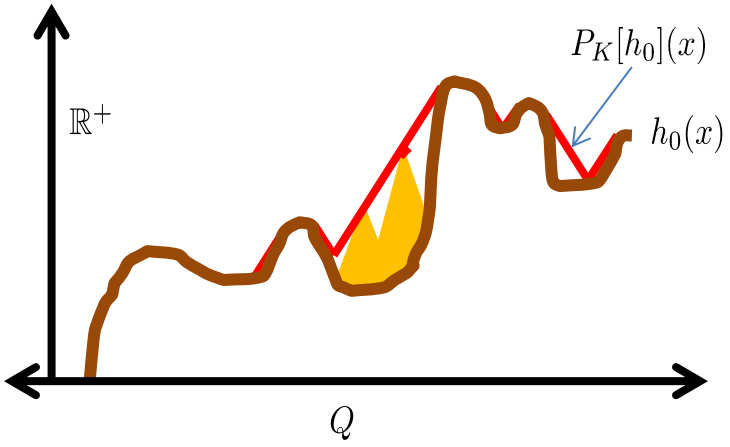


Stopping for Algorithm 1

Bounded above

Depositions never add material above $P_K[h_0]$



Proof based on point selection,

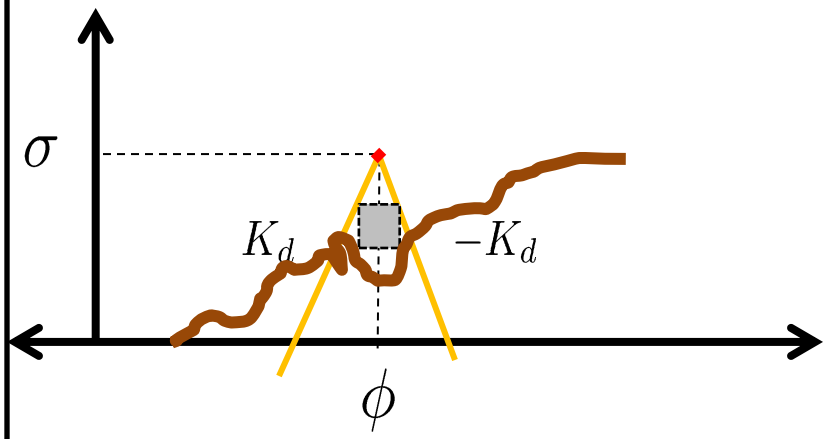
$$\sigma \in [h_n(y') + \epsilon, h_n(y) - h_n(y') - K|y' - y|]$$

and the inequalities

$$h_n \leq D[f_{(\phi,\sigma)}, h_n] \leq P_K[h_n] = P_K[h_0].$$

Guaranteed progress

Each deposition has a minimum Volume.



Proof based on point selection,

$$\sigma \in [h_n(y') + \epsilon, h_n(y) - h_n(y') - K|y' - y|]$$

and deposition steepness K_d and continuity assumptions on $h_n(x)$.

Adaptive Ramp Building (Alg 2)

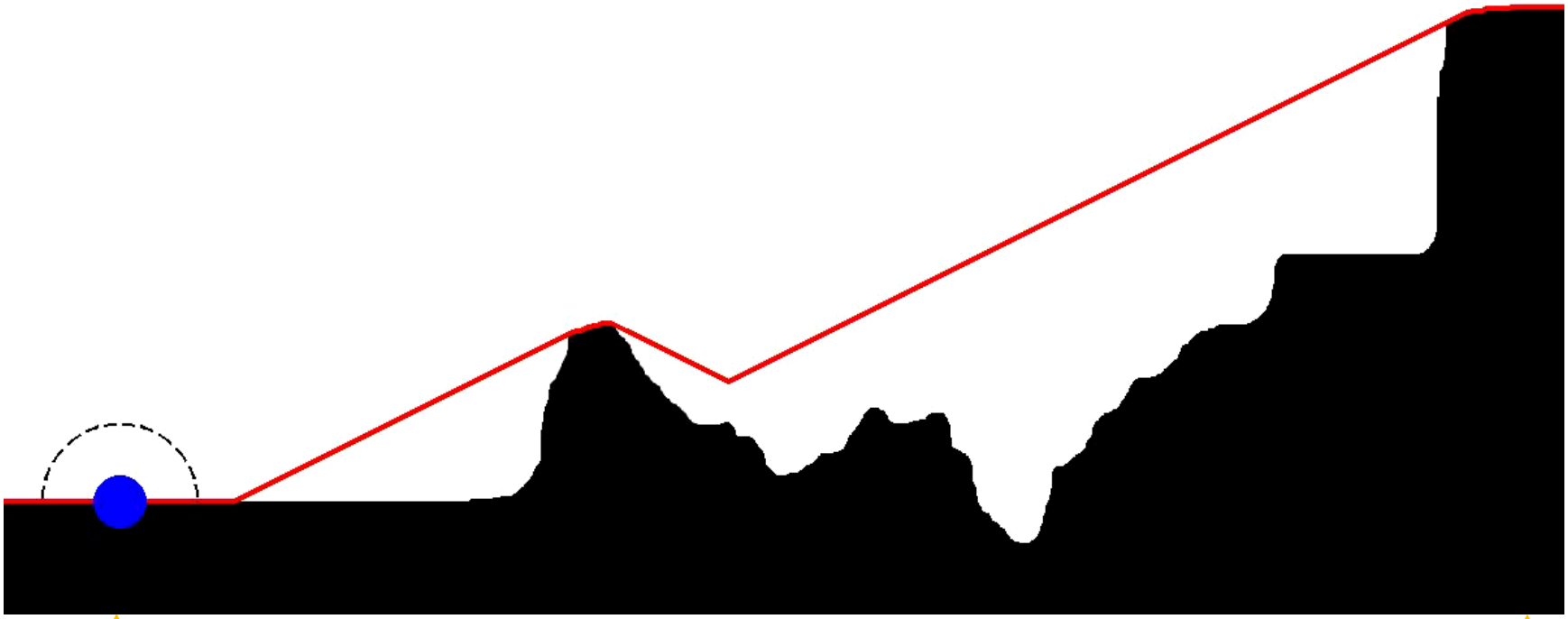
Algorithm 2

1. Given $h_0 \in \mathcal{Q}^+$, $x_0, x_* \in Q$ and navigable terrain around x_0.
2. Set $x = x_0$
3. While $x \neq x_*$
4. Move until $\exists y \in [x, x+r]$ $s.t.$ $y, x+r$ are non-navigable or $x = x_*$
5. If $x \neq x_*$
6. Move to lower point and deposit according to Alg. 1
7. Move backward to $x = x - 2r$
8. EndIf
9. EndWhile

Proof based on termination of Alg.1 and backing up from depositions that might have altered previously navigable terrain.

WYSS

Adaptive Ramp Building



Start

426 Steps

Goal

N. Napp and R. Nagpal, **Distributed Amorphous Ramp Construction in Unstructured Environments** . DARS 2012

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Using Algorithm 2 in 3D

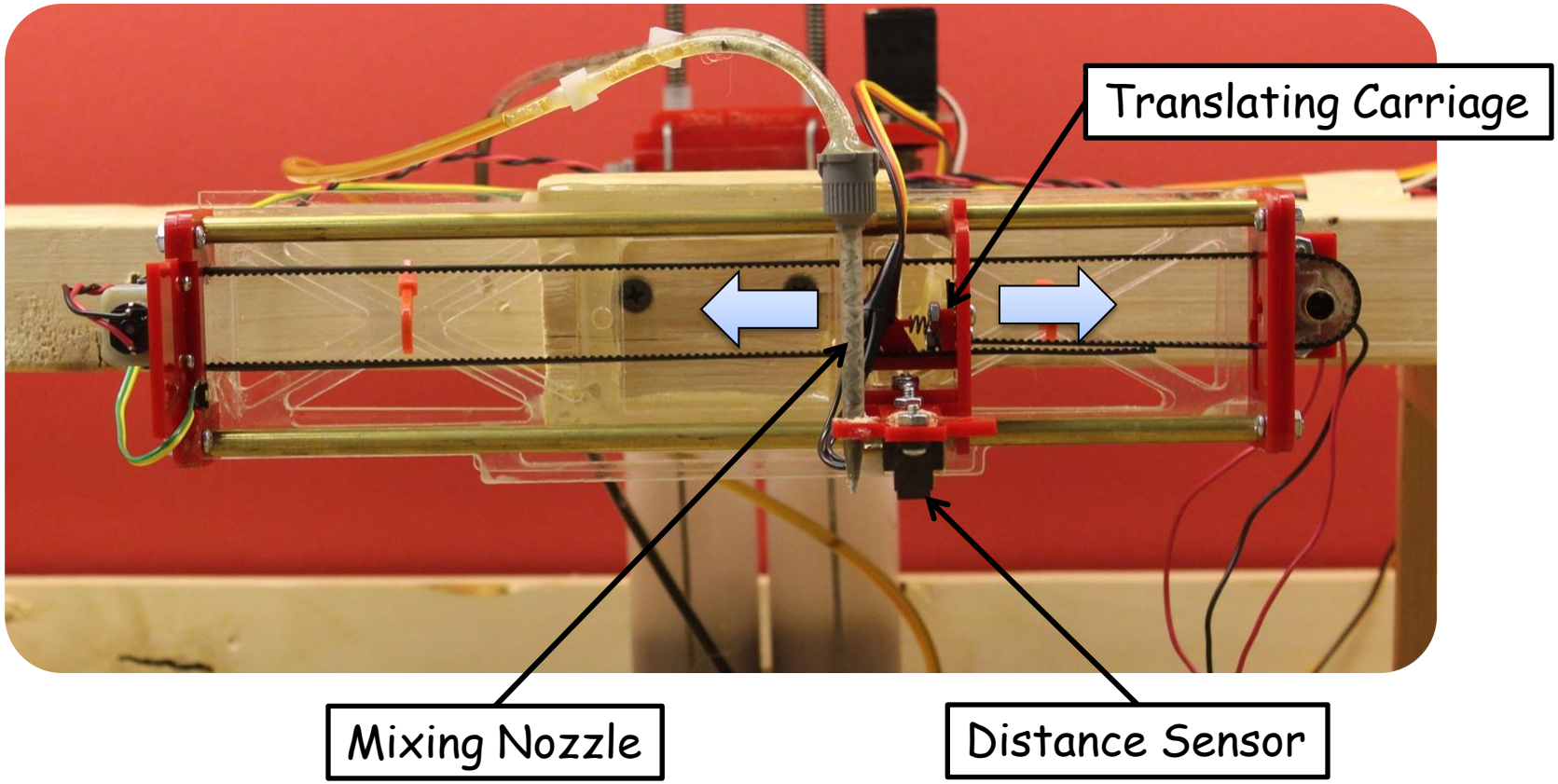
Leveling Mechanism

Level Deposition with Conical Cross Section

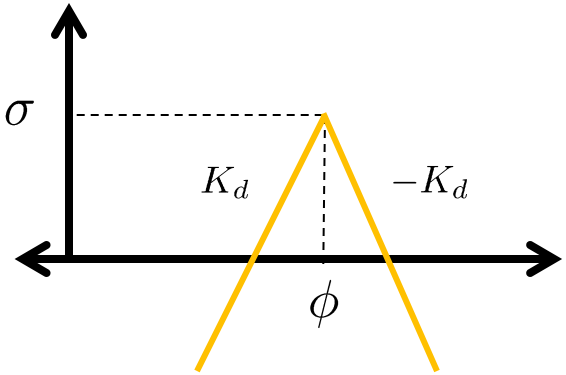
$\mathbb{R}^+$

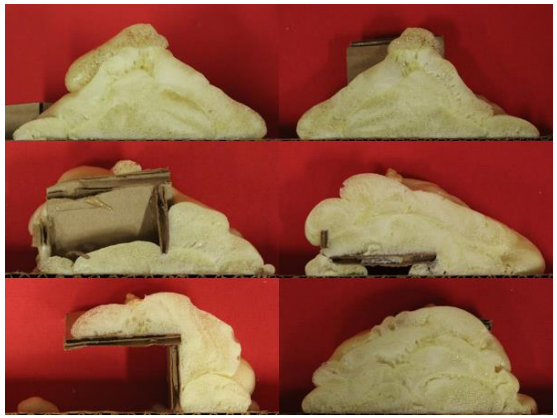
Q

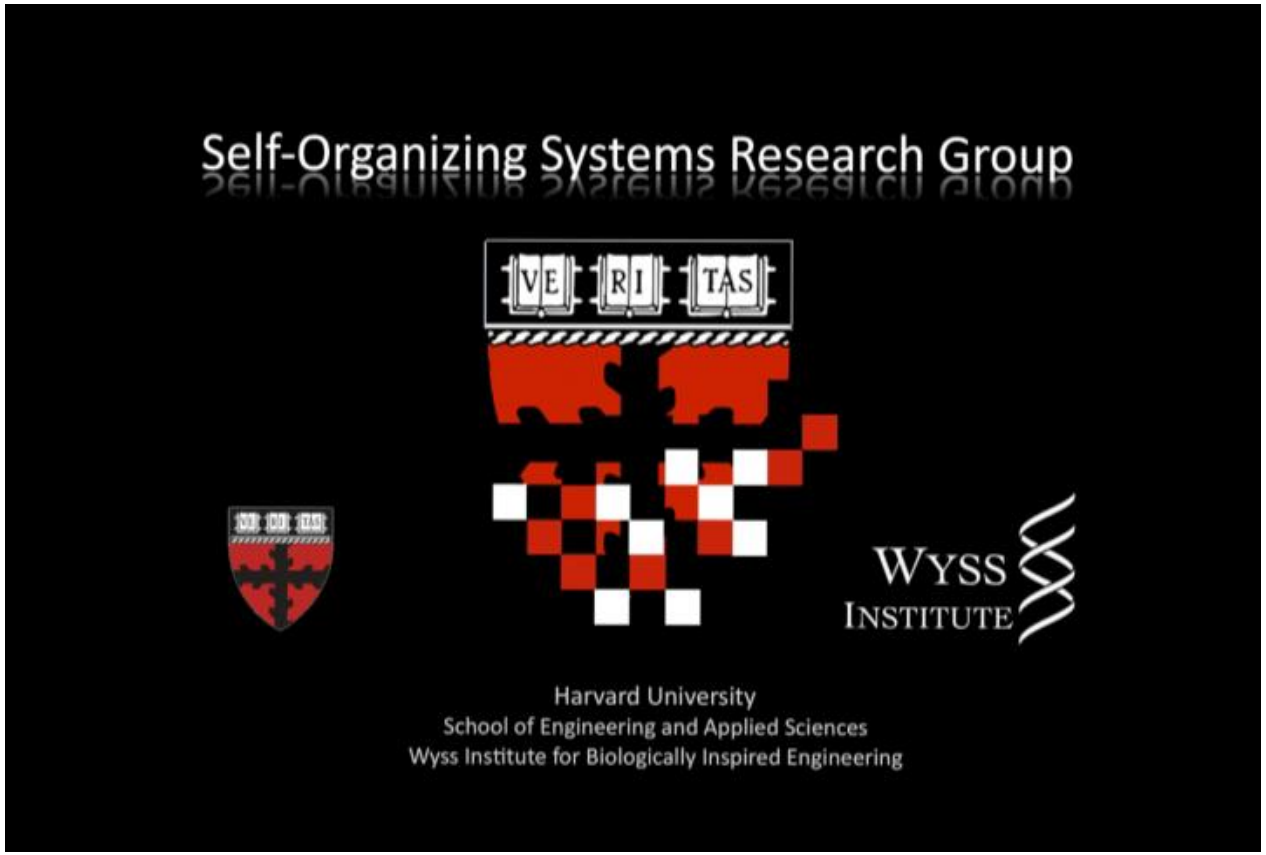
Experiment: Messy Leveling



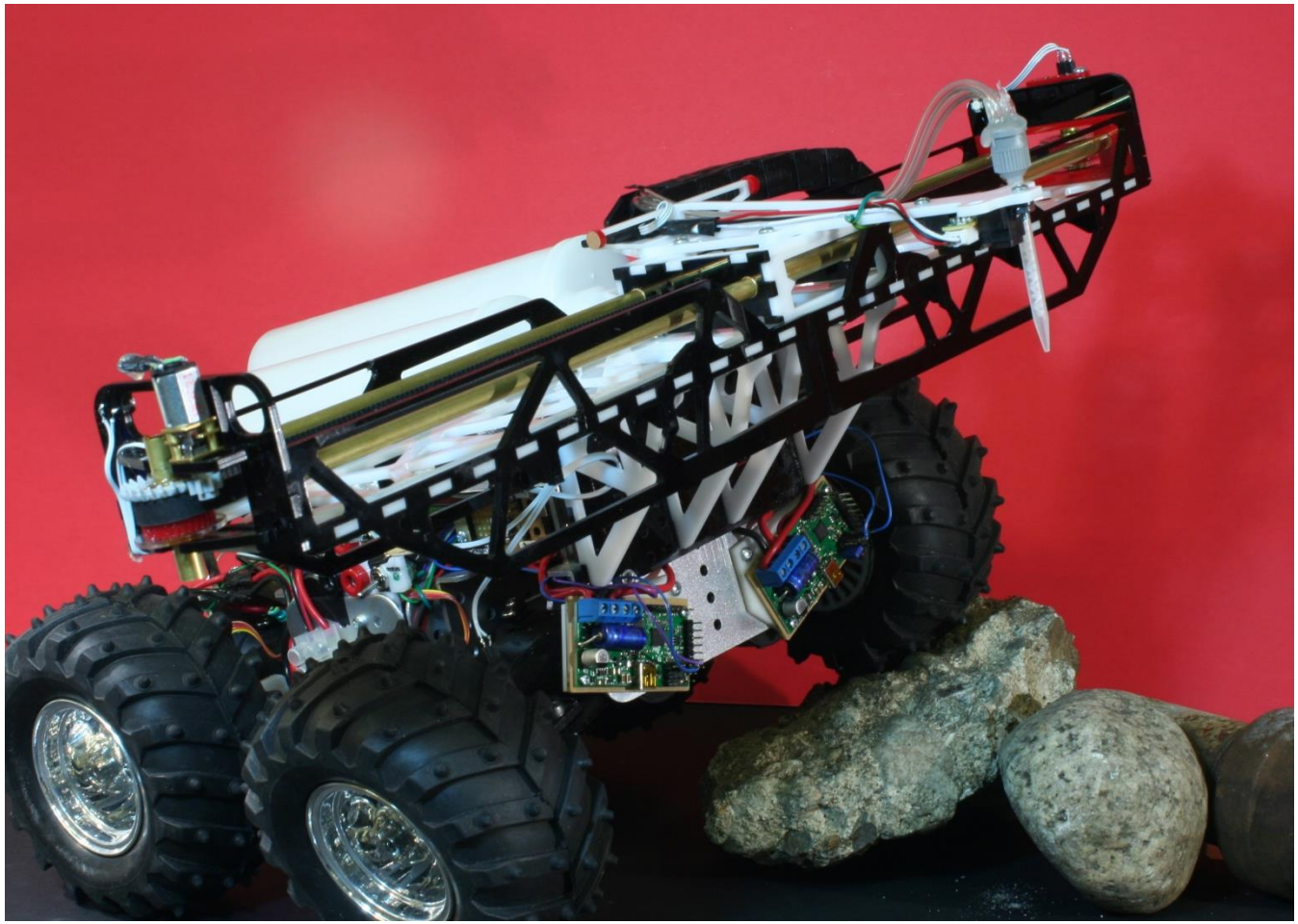
Experiment: Messy Leveling



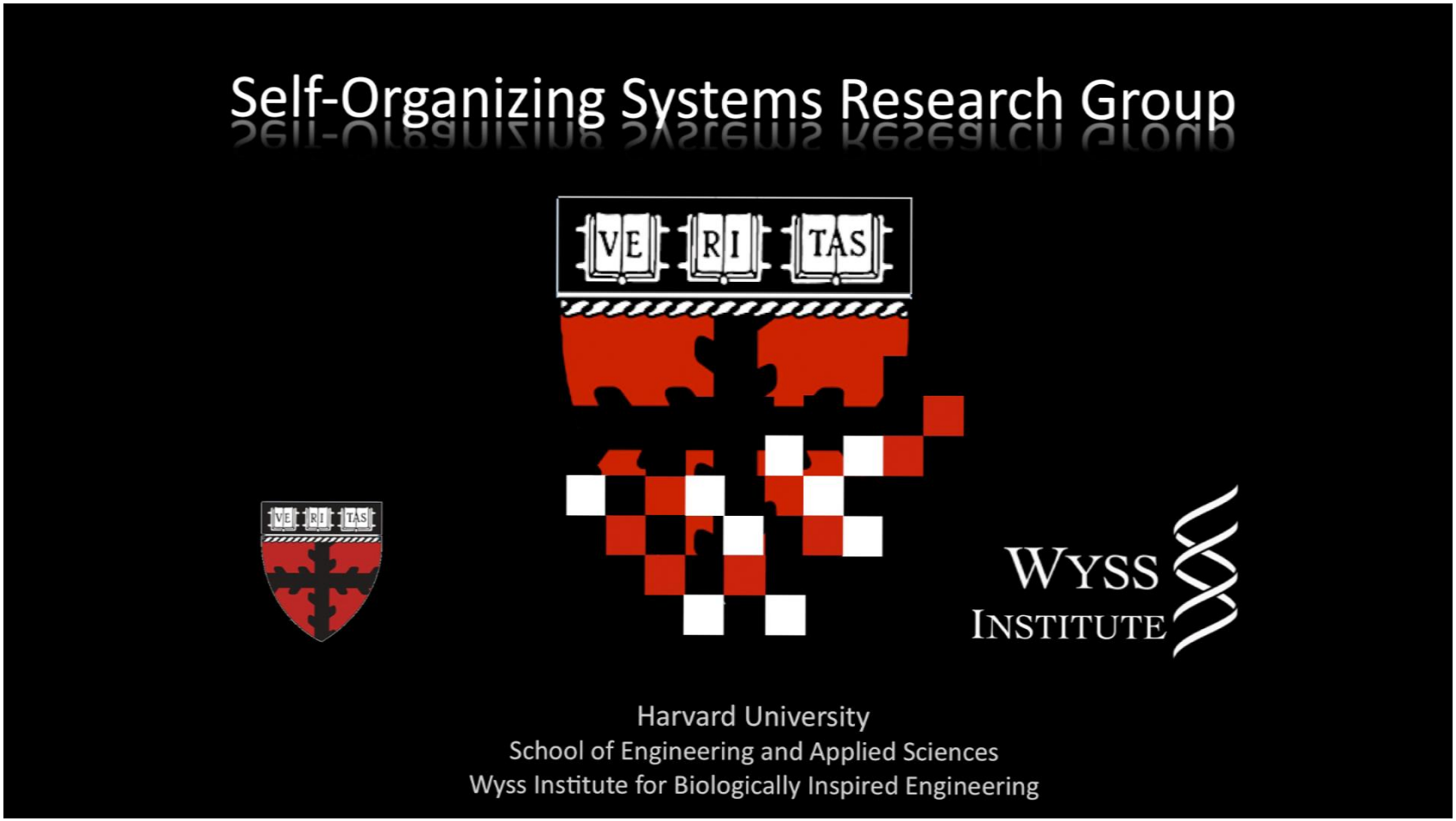




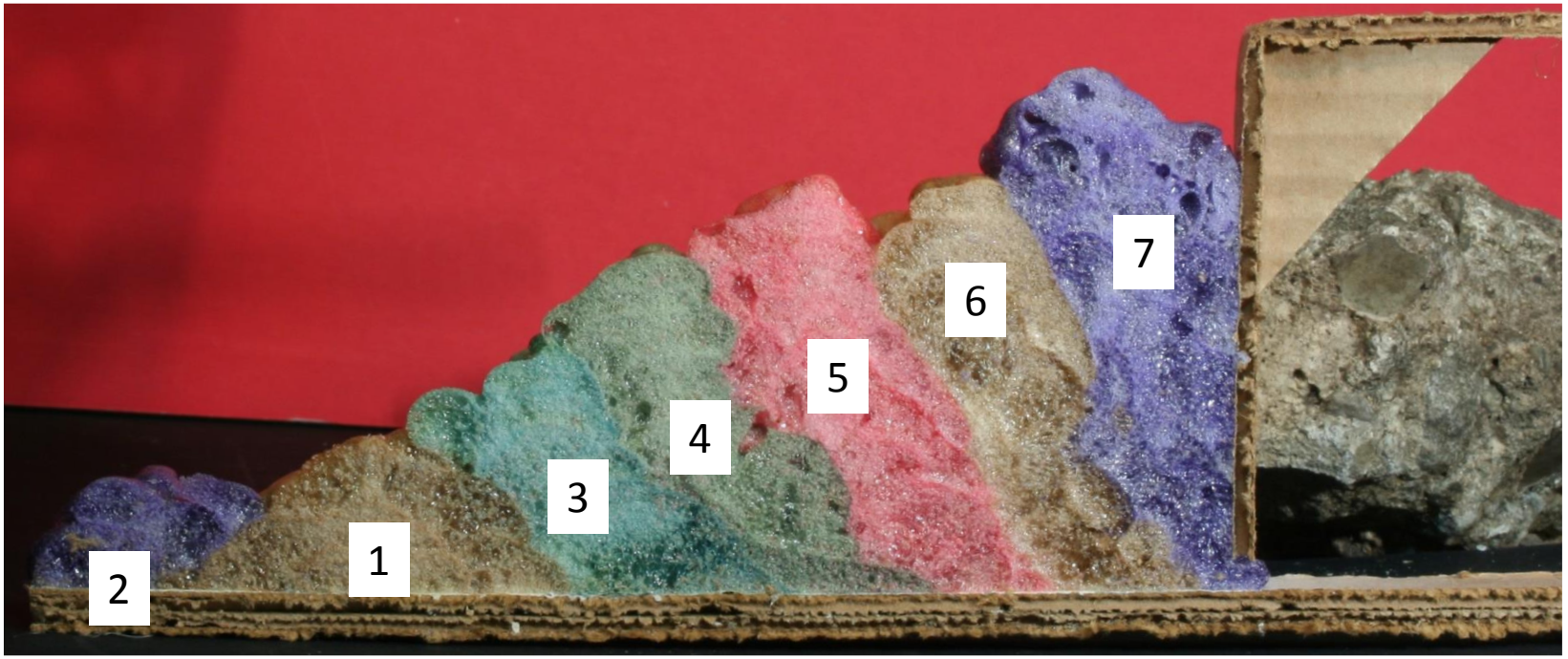
Foam Depositing Robot



Robot Depositing Foam

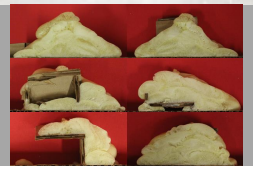
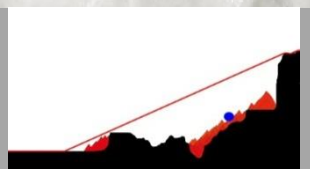


Foam Ramp

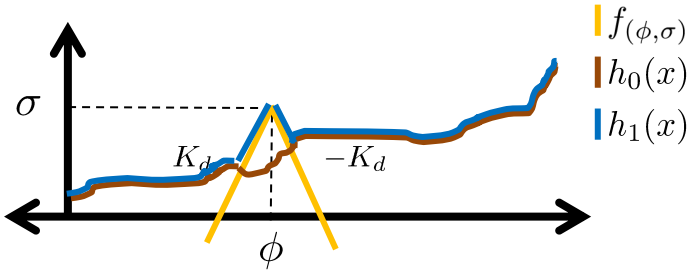


Summary

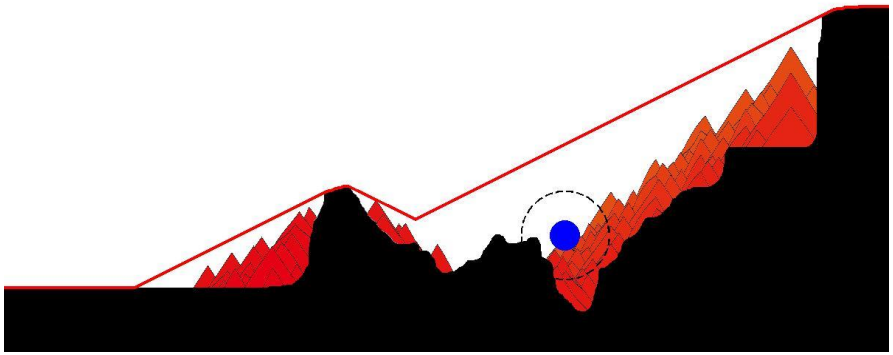


- Amorphous building materials can enable robust construction in irregular terrain
- Model terrain with continuous functions
- Bound shape uncertainty with shape functions

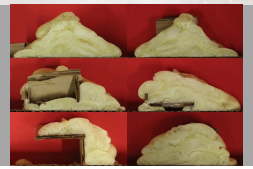
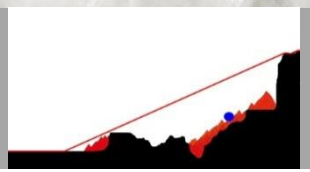


$$D[f_{(\phi,\sigma)}, h_n](x) = \max\{f_{(\phi,\sigma)}(x), h_n(x)\}$$

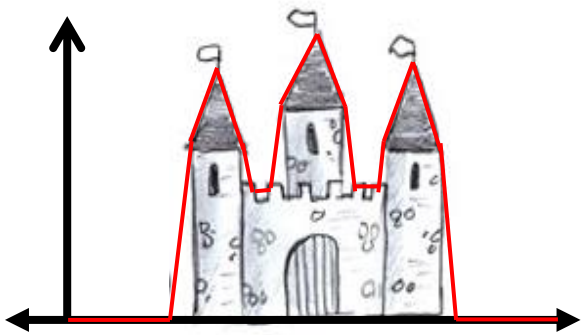
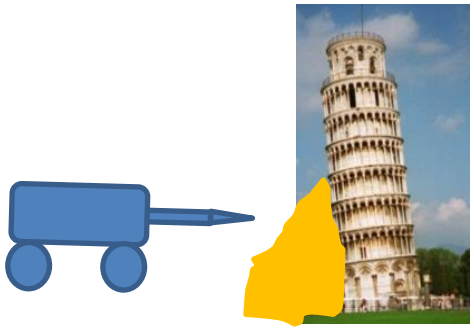


Future Work
Construction in Cluttered Terrain



- Use models to build other structures
- Reliable construction with found objects
- Extend to probabilistic setting


At UB

- **Teaching CSE 668: Advanced Robotics**
  - **Spring 2015 (MWF 12:00pm)**
  - **Previously called (Animate Vision Principles)**
- **Looking for Students**
  - **Take my class/work on a project with me**
  - **E-mail: nnapp@buffalo.edu**
  - **Office hours: Tue/Thur 10:00-11:00am**