Mitra Research Group Meeting

Alli Nilles

October 9, 2017

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- **Bouncing robots:** discovering (and proving) dynamical properties of simple robot motion models

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- **Automatic robot design** and automation of Robot Design Game

General Approach to Robot Decisionmaking

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- can create filters, planners over information spaces (good for when we don't know, or don't need to know, physical state space)
- **task specific** design: how to specify tasks?

Mobile Robots

- many mobile robot tasks are actually properties of the path the robot takes through space

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- coverage, environmental monitoring, patrolling, navigation
- many simple models of mobile robot motion
- which ones have nice dynamical properties that we can get "for free" (without a lot of feedback control)?

Blind, Bouncing Robots

Model the robot as a point moving **in straight lines** in the plane, "bouncing" off the boundary at a **fixed angle** θ from the normal:

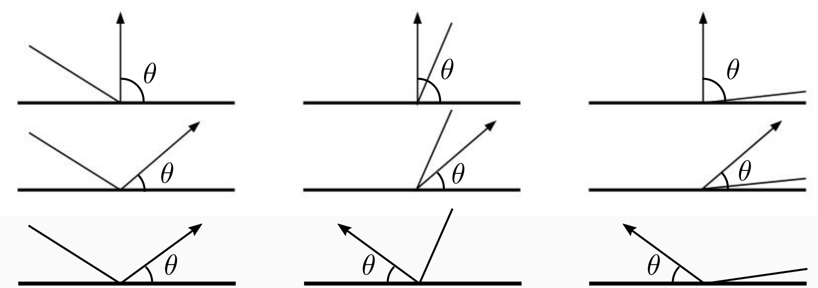

Figure 1: A point robot moving in the plane. The top row shows bounces at zero degrees from the normal. The second row shows bounces at 50 degrees clockwise from normal. The third row shows the same angle but with a "monotonicity" property enforced.

Trapping or Coverage Properties

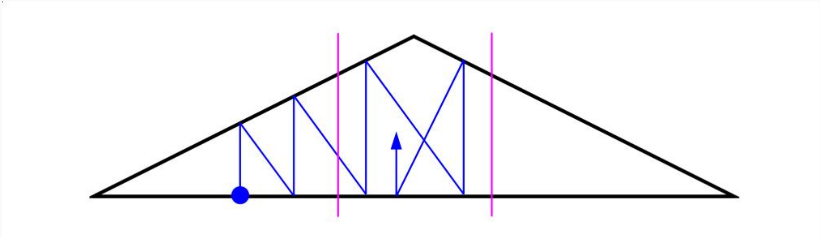

Figure 2: In this environment, bouncing at the normal, the robot will become trapped in the area between the purple lines.

Implementation

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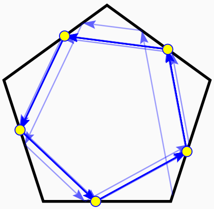
- Can implement on a roomba with bump sensor and IR prox detector[1]
- "Collisions" can be virtual - for example, robot w/ camera stops when it is collinear with two landmarks, and rotates until one landmark is at a certain heading
- Also useful model of very small "robots" or microorganisms,[2] or robots in low-bandwith environments

[1] [1], Lewis & O'Kane IJRR 2013
[2] [2], Thiffeault et. al. Physica D Nonlinear Phenomena 2017

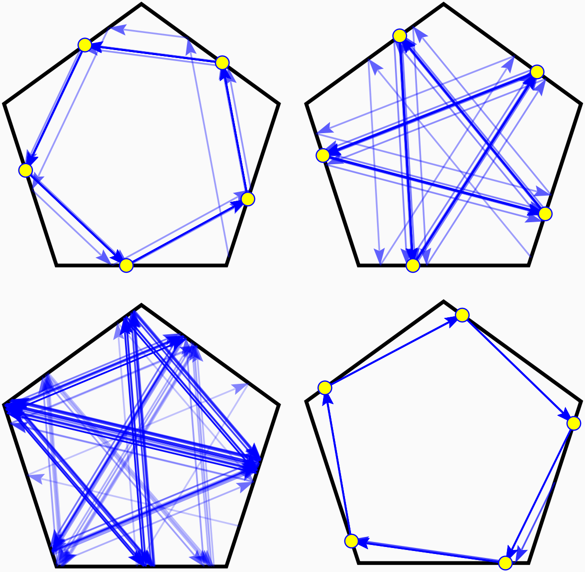
Discovery Through Simulation

- Haskell with *Diagrams* library [3]
- fixed-angle bouncing, specular bouncing, add noise
- render diagrams from simulations automatically[3]

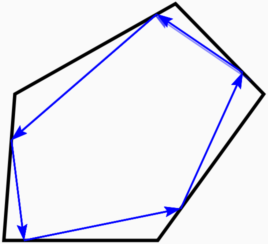


[3] https://github.com/alexandroid000/bounce

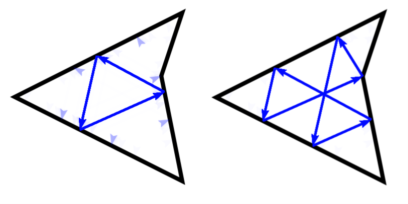
Simulation Results



Other Polygons



(a) A stable orbit in a sheared pentagon.



(b) A stable orbit in a nonconvex environment.

Figure 4: Stable orbits also exist in non-regular polygons.

Goals

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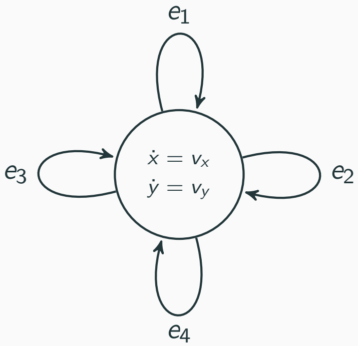
- minimize simulation / discretization / floating point artifacts
- synthesize controllers (bounce angles + some transition condition, depending on sensors)

584 Project - Reachability in 2D with SpaceEx

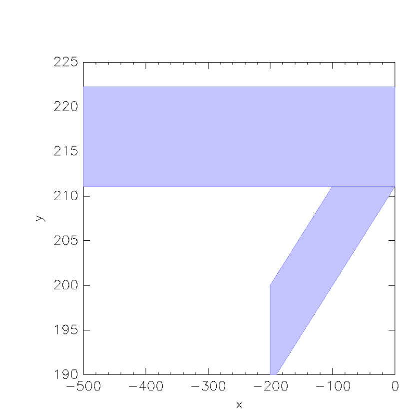
code generation for given polygon and bounce angle

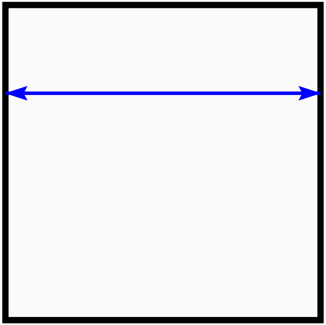


Results of Simulations

When bouncing between parallel sides, SpaceEx finds fixed point within a few iterations!

This type of bouncing is geometrically exact: $f_{1,3}(f_{3,1}(x)) = x$ if $f_{i,j}$ is the mapping from side e_i to side e_j.





Results of Simulations - Nonconvergence w/ Asymptotic Stability

When periodic orbit is asymptotically stable, SpaceEx does not appear to converge, even when trajectories should (mathematically) always return to same interval

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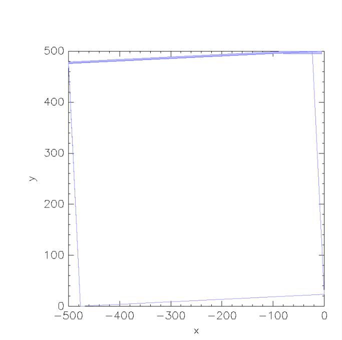

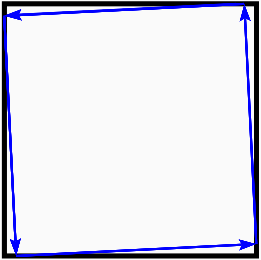

The Synthesis Problem

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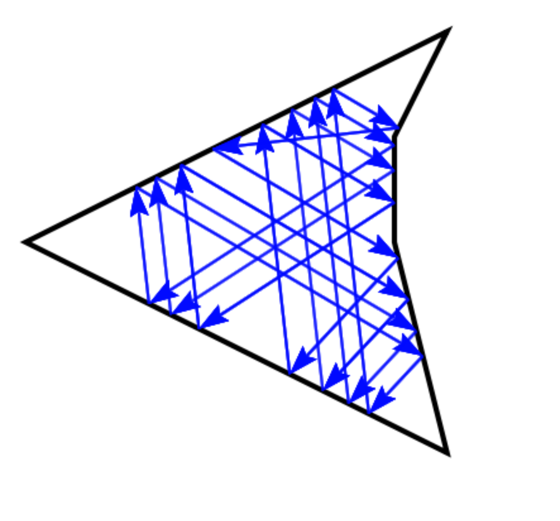
- Use this as subroutine for synthesis algorithms: given environment, what bounce angles produce paths with certain properties (coverage, limit cycles)?
- Stability detection with reachability (if robot starts in interval on edge i, show it will not reach the complement of that interval)
- Modelling / synthesizing strategies over multiple angles (generate multiple automata and compose)

Results

- For synthesis: is exponential blow-up going to be a problem?



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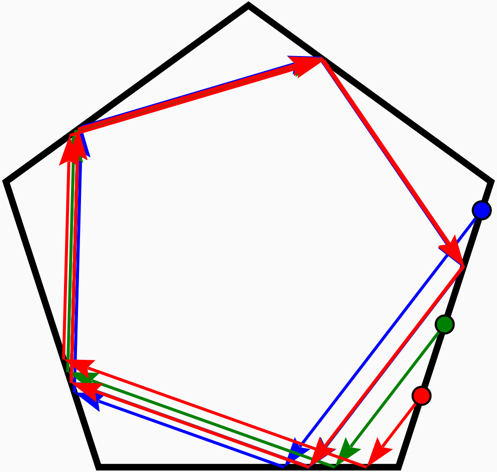
- Incorporate minimal feedback control (what if we have a pebble, colored walls, laser beams, etc) and information space representation
- balance between small modelling distance (1D) and generality for other motion primitives (2D)

Questions / Comments?



Acknowledgements: Samara Ren, Michael Zeng, Israel Becerra, Steve LaValle

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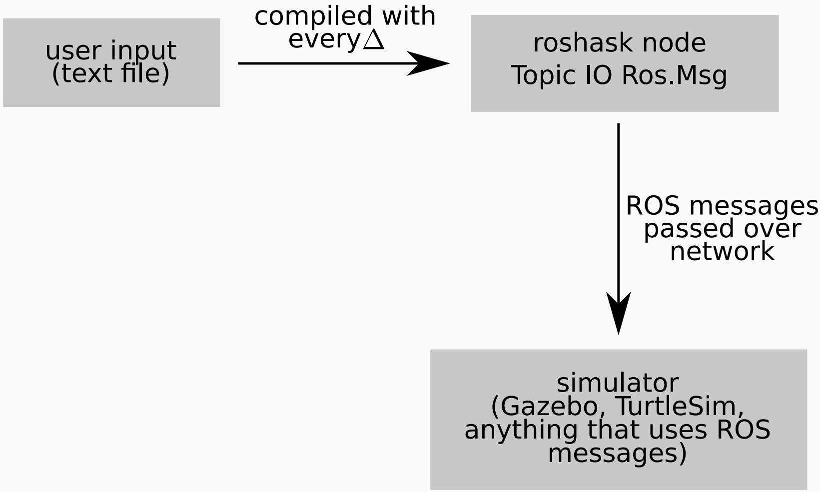
(show video)

Architecture Overview



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What is live-coding?

- Usually has a performance/improvisational connotation
- requires low latency / flow

Problem $\Longleftrightarrow$ Program

```python
if __name__ == '__main__':
    pub = rospy.Publisher('turtle1/cmd_vel',Twist)
    rospy.init_node('publisher_node')
    loop_rate = rospy.Rate(5)
    while not rospy.is_shutdown():
        vel=Twist()
        vel.linear.x = 1.0
        vel.angular.z = 1.0
        pub.publish(vel)
        loop_rate.sleep()
```

Two Issues in Creating Robotic Motion

Live coding (with a motion DSL) addresses

1. confusing workflow for beginners
   - large number of steps required
   - order of steps unclear
   - hard to install programs
2. bad mapping between problem domain and program domain
   - have to "translate" our representation of task into software semantics

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Formal methods and verification can help with step 2, as well as help provide informative feedback when something goes wrong.

Using roshask[4]

- Haskell client library for ROS
- interpret DSL to a Haskell ADT representing a movement pattern
- convert to ROS message

```
mkTwist :: VelCmd Double -> Twist
mkTwist (VelCmd t r) = def  & angular . V.z .~ r
                            & linear . V.x .~ t
```

[4] [4]

The Modelling Problem

How to model motion in a way that is amenable to a simple, high-level DSL?

A Detour into Monoids

A *monoid* is a set S along with a binary operation $\diamond :: S \to S \to S$ and a distinguished element $\epsilon :: S$, subject to:

$$\epsilon \diamond x = x \diamond \epsilon = x$$

$$x \diamond (y \diamond z) = (x \diamond y) \diamond z$$

for all $x, y, z \in S$.

Why think about monoids? [5]

- Simple algebraic model of composition
- Can show common structures, build up abstraction quickly

Monoids

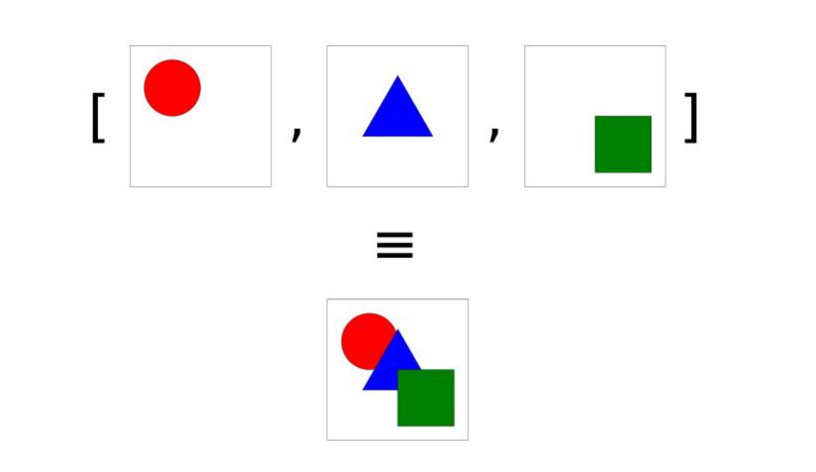

Figure 5: Composing a list of *Diagrams* primitives [5]

Data Structures - Space

```haskell
data Dance b = Prim Action Mult b
             | Rest Mult
             | Skip -- id for series, parallel
             | Dance b :+: Dance b -- in series
             | Dance b :||: Dance b -- in parallel
       deriving (Show, Eq, Read)
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-- map over parts (for changing platforms)
instance Functor Dance where
    fmap f (x :+: y) = (fmap f x) :+: (fmap f y)
    fmap f (x :||: y) = (fmap f x) :||: (fmap f y)
    fmap f (Rest m) = Rest m
    fmap f (Skip) = Skip
    fmap f (Prim act m part) = Prim act m (f part)
```

Robot-Specific Specification

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robotRes = 100 :: Mult -- messages/second, ROS publishing r
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- Inspired by choreography and by *Dance* [6]

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- `repeat`, `reflect`, `reverse`, `retrograde`

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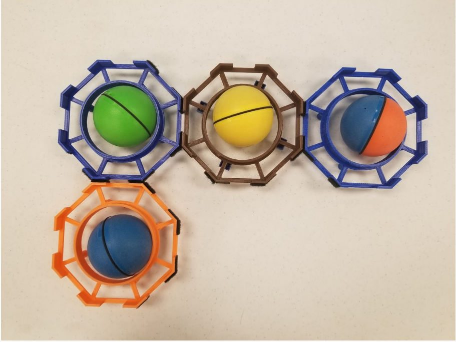
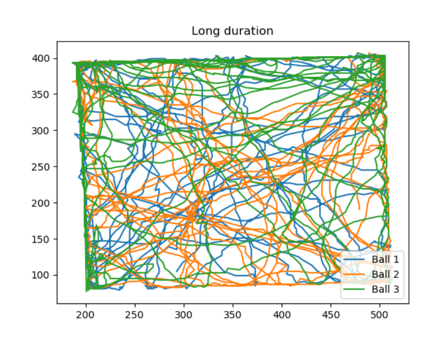
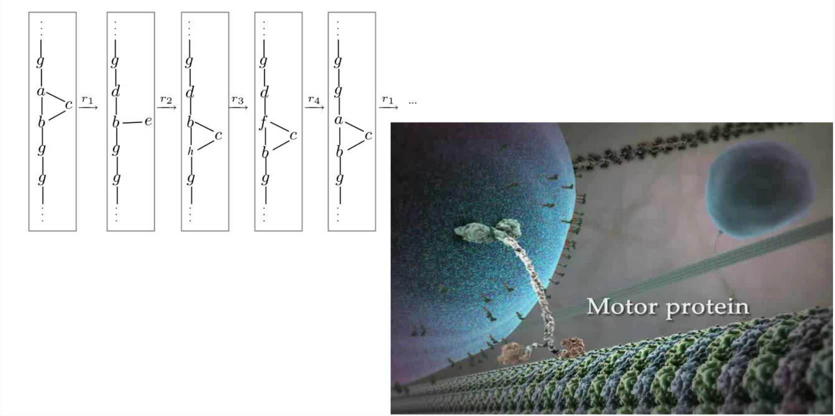
- could model Improv DSL in K and have some model of what the simulator is doing (DryVR). How modular is Koord / K / DryVR implementation?

Self-Assembly and Aggregate Robotics



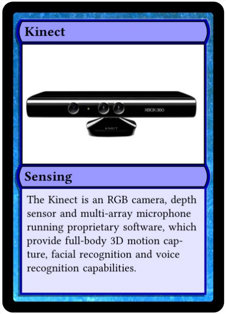


Goal of Repeatable, Non-Reversible Motion



Is it possible to synthesize local interaction rules which lead to this type of motion?

Automatic Robot Design



2016 and 2017 RSS workshops on minimalism and automated design

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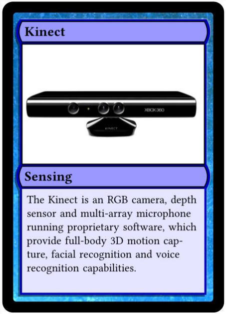

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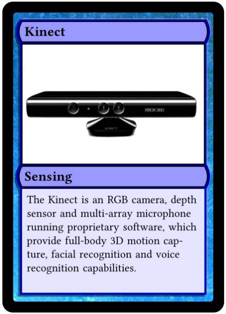

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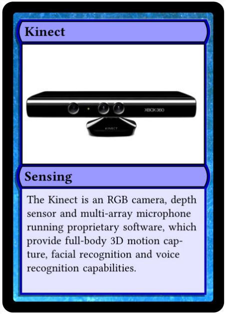

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www.robot-design.org

References

[1] J. S. Lewis and J. M. O'Kane, "Planning for provably reliable navigation using an unreliable, nearly sensorless robot," *International Journal of Robotics Research*, vol. 32, no. 11, pp. 1339–1354, September 2013.

[2] S. E. Spagnolie, C. Wahl, J. Lukasik, and J. L. Thiffeault, "Microorganism billiards," *Physica D: Nonlinear Phenomena*, 2017.

[3] B. A. Yorgey, "Monoids: Theme and variations (functional pearl)," in *ACM sigplan notices*, 2012, vol. 47, pp. 105–116.

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