Artisan's ASYLUM

Robotics Intensive:
Rideable Hexapod

Gui Cavalcanti, Dan Cody, James Whong

4/17/2012

Presentation Overview

- Wait, what is this place?
- Who are these guys?
- Oh God, what have I signed up for?
- What are we building?
- How on earth are we building it?

What is this place?

What is this place?

- Artisan's Asylum, Inc.
- Nonprofit community workshop
- 31,000 square feet
- Multiple craft areas
  - Welding, machining, metalworking, woodworking, electronics assembly, sewing, bicycle repair...
- 20-25 classes a month

Who are these guys?

Who are these guys?

Gui Cavalcanti **Dan Cody** **James Whong**

Who are these guys?

- Olin College of Engineering grads
- Professional roboticists
- Crazy motherfuckers

Gui Cavalcanti

- **Mechanical/Systems Engineer**
- **Formerly systems integrator for a $35M, 1,200 pound hydraulic robot horse**
- **Worked on BigDog, PETMAN, LS3 and more**
- **Co-founder and President of Artisan's Asylum**
- **Makes giant rubber duckies, floating bouncy castles, and dragon sculptures for fun**

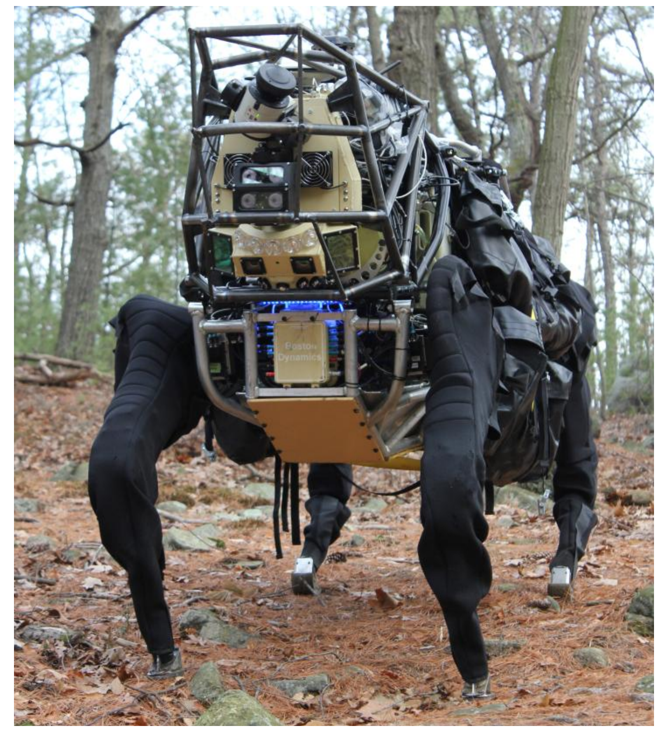
Dan Cody

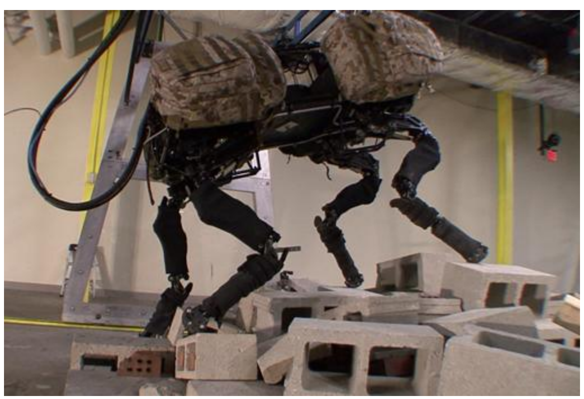
- Controls/Electrical Engineer
- Designer and author of libbarrett, open-source real-time controls library behind WAM arm
- Worked on Barrett's WAM arm, DEKA's Luke arm, and more
- Currently a controls engineer at Barrett Technologies
- Dangles from cliff faces for fun

James Whong

- Electrical/Controls Engineer
- Designed distributed electrical control infrastructure for several Boston Dynamics robots
- Worked on PETMAN, RCTA, ATLAS, and a number of robots for DEKA, Vision Robotics, and others
- Currently an electrical engineer at Boston Dynamics
- Hates fun

Projects We've Worked On





Our Roles

- **Instructors:**
  - Teach you how to accomplish project goals
  - Create exercises to guide you through the design process
  - Critically evaluate and give feedback to your designs and ideas
- **Project Managers:**
  - Keep the whole project moving and relatively on-schedule
  - Make high-level systems decisions and review low-level detail decisions
  - Find and allocate money, time, energy, etc. in the pursuit of ridiculousness
- **These will sometimes conflict, we need your help to resolve this**

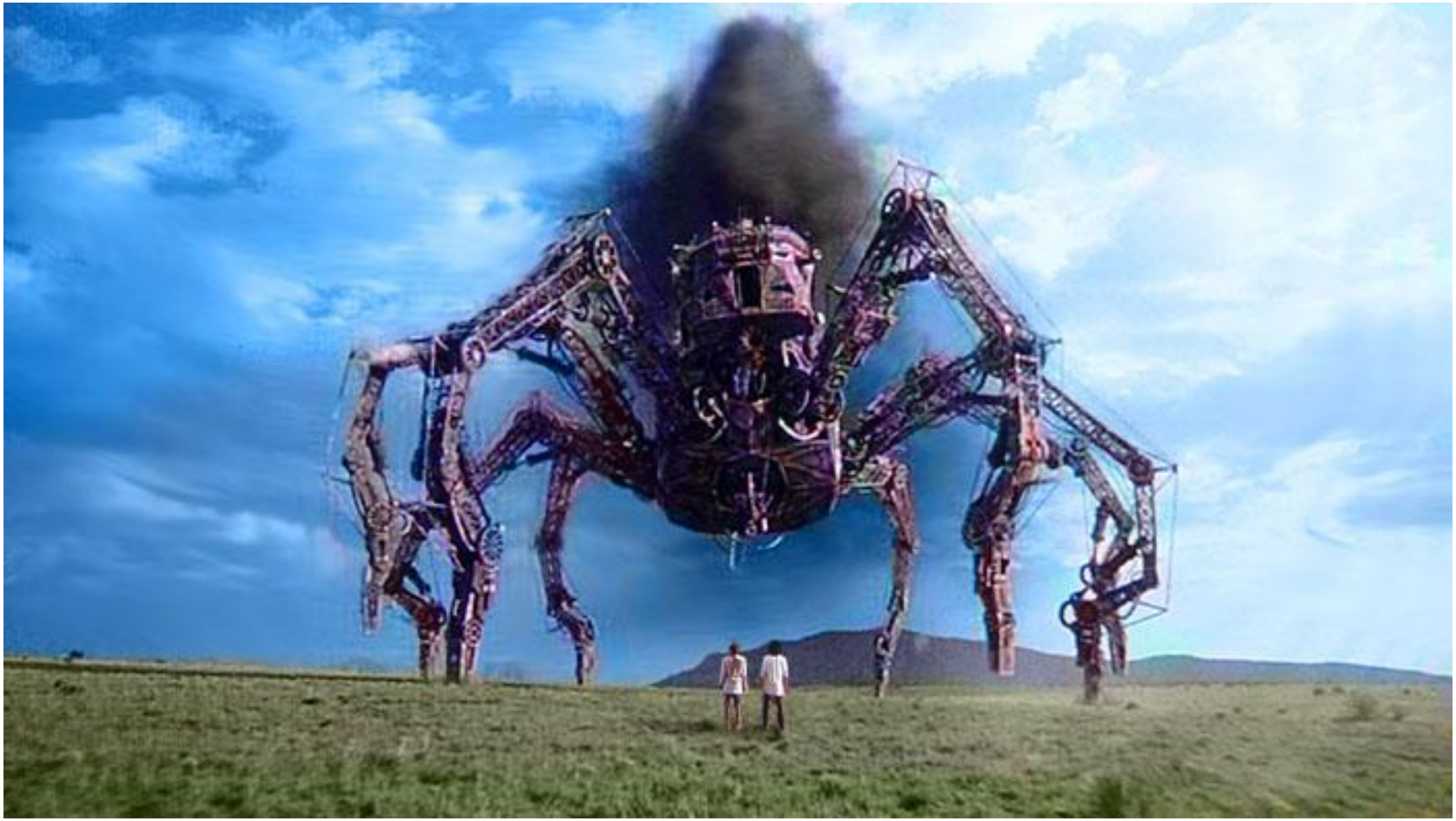
Who are you?

Who Are You?

- What's your name?
- What's your background?
- Why do you like robots?
- What are you hoping to get out of the class?

What have I signed up for?

What you've signed up for.



A Grand Experiment

Public, project-based education

A Grand Experiment

- **Robots take a ton of the following:**
  - **Money**
  - **Time**
  - **Energy**
  - **Informed, correct decisions**

A Grand Experiment

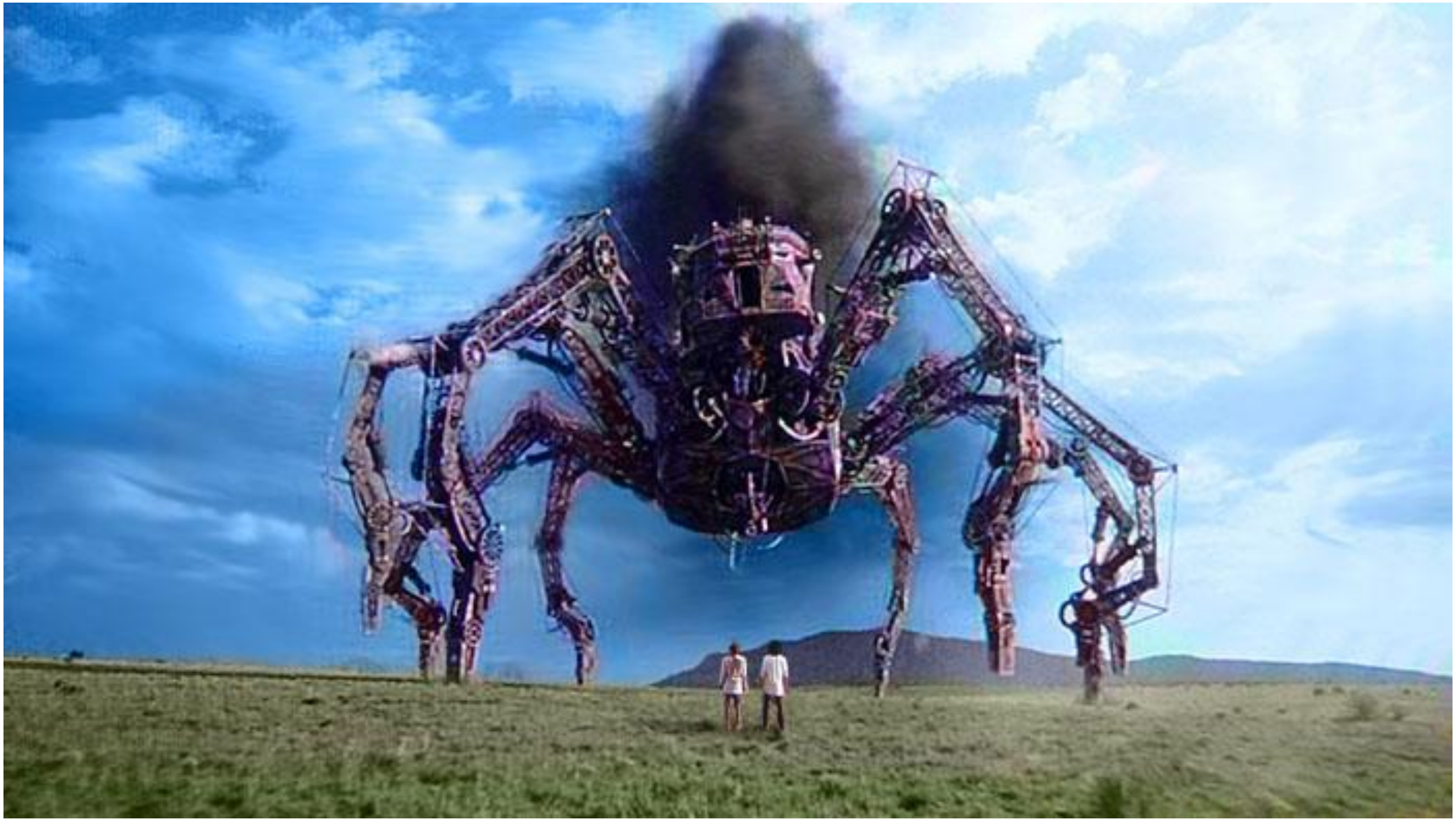
- Classes provide
  - Income from tuition
  - Fixed, recurring, devoted time with a large group
  - Energy for learning and creating
  - Decision-making infrastructure

A Grand Experiment

- Design a class to create a giant hexapod
  - Class income provides $10,000+
  - Fixed time slots demand recurring attention, large class has a ton of productive capacity
  - Students get to learn exactly how robots are designed, and practice doing the heavy lifting
  - Instructors/project managers get to guide a successful project to completion
- Everybody wins!

What are we building?

What are we building?



Actually, more like…

Artisan's ASYLUM

Design Goals

- 1-2 person payload
- Inherently stable, “safe”
- Walk at 3-4mph
- Run for an hour at a time
- Make people go “wow”

Design Contraints

- Money + Time
  - We have 2 orders of magnitude less than most professional robotics projects
  - We need to use as much prior art as possible

Building blocks

- Morphology
- Actuation + Transmission
- Powerplant + Energy Storage
- Structural
- Sensing + Electronics
- Controls

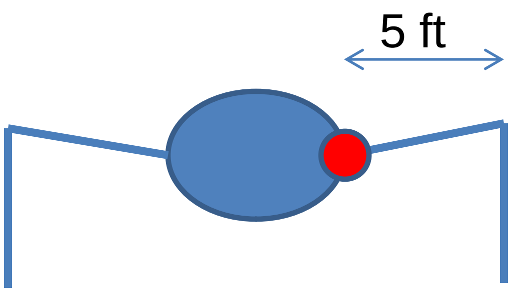
Morphology: 6 Legs

- Statically stable gait
  - Behaves “safely” if stopped mid-cycle
  - “Impossible” to tip over
- Allows for several simple gaits
  - Alternating tripod
  - Ripple gait
- Spreads load out over many legs
- Simple inverse kinematics

Morphology: 18 DOF

- DOF = Degree of Freedom
  - Your elbow is one DOF, your shoulder is three
- To place a foot in 3D, you need 3 actuators/DOF
- We have 6 feet
- 6 legs X 3 DOF/leg = 18 DOF

Actuation + Transmission

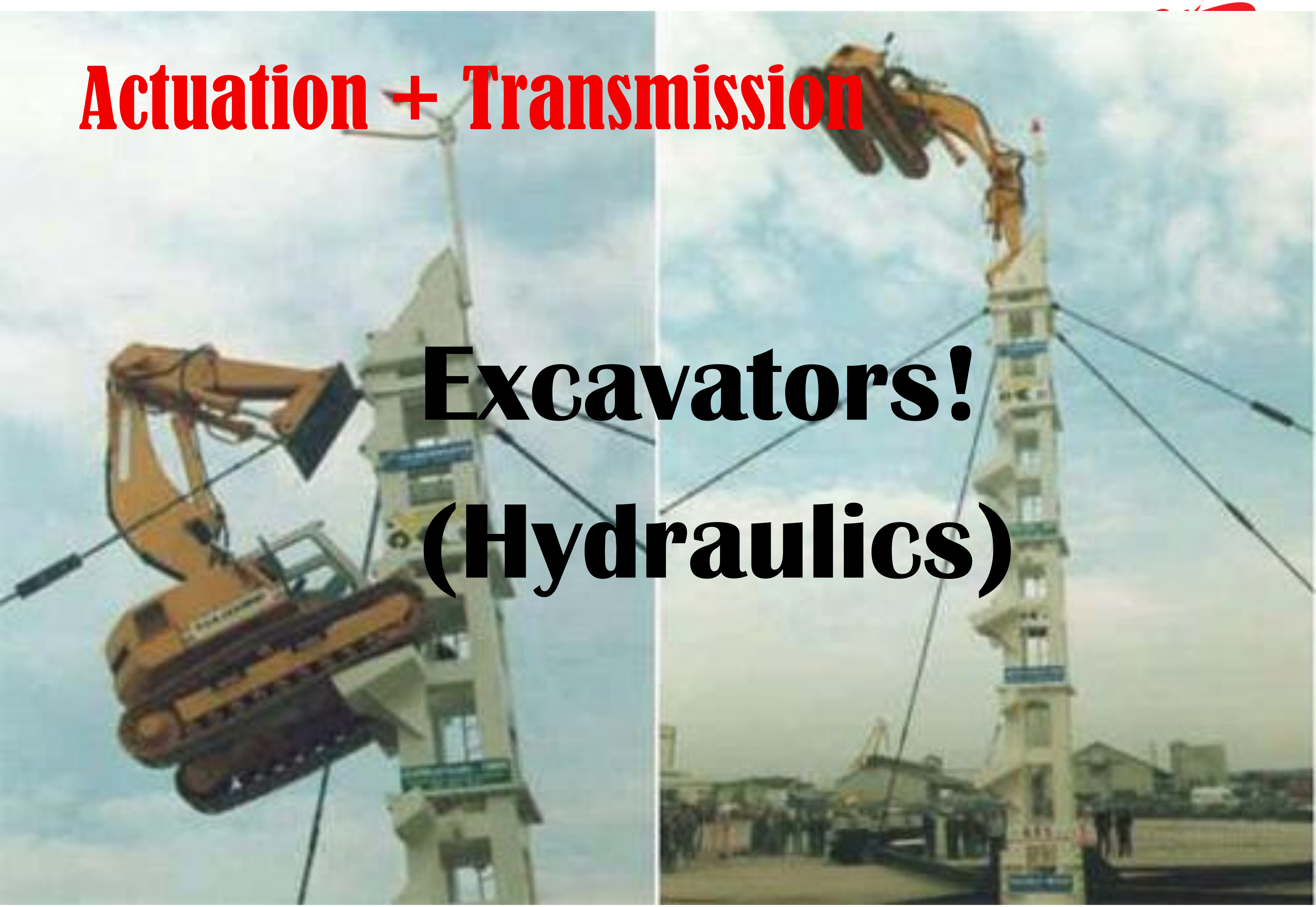


- A 5 foot leg extension (low estimate) with 600 lbs downforce = 3,000 lb*ft
  - The torque on the wheel of your car in first gear is ~150 lb*ft
  - Effectively rules out electric motors

Actuation + Transmission

- **What vehicles produce torque of these magnitudes?**

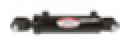
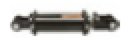
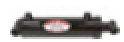
Actuation + Transmission



Excavators!
(Hydraulics)

Actuation + Transmission

- **Hydraulics**
  - Cheap
  - Available
  - Reliable

Hide Pics	Sort Descriptions: Alphabetically or by Size	In Stock	Sort by Price	Qty to Buy
	1.75x15x1.5 DA HYD CYL GMI 2538 Item# 9-9265	66	$74.95	1
	2x2.5x1 DA HYD CYL TAPPED BASE END Item# 9-9880	7	$49.95	1
	2"X4"X1.125" DA HYD CYL HEAVY DUTY CLEVIS Item# 9-7715-4	27	$108.95	1
	2X4X1.125 DA HYD CYL W200040 Item# 9-7940-4	37	$55.95	1
	2X4X1.25 DA HYD CYL 1 PINS HVY DUTY CROSSTUBE Item# 9-7710-4	17	$115.95	1
	2X4X1.25 216-674 2004WT DA HYD CYL 1" PINS Item# 9-6466-04	8	$134.95	1
	2X4X1.25 216-700 2004WT DA HYD CYL 3/4" PINS Item# 9-5250-04	6	$134.95	1

Powerplant + Energy Storage

- Provide hydraulic power
- Indoor/outdoor operation
- Don’t have time to DIY
- Need high reliability
- Need safe fuel system

Actuation + Transmission

- **What vehicle powerplants provide this?**

Powerplant + Energy Storage

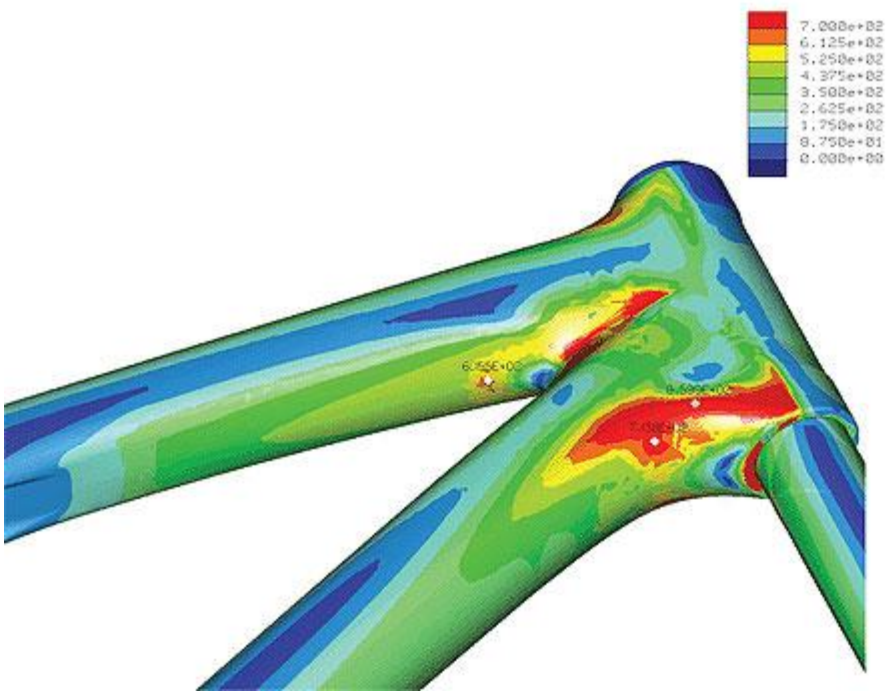
- **Forklifts!**
  - **Propane engine clean to run inside**
  - **Fuel comes in rugged canisters**
  - **Engine and hydraulic pump are one unit**
    - **And we got one**

Force-Controlled

- We have 6 legs that look like excavators
- Excavators are designed to dig into the ground
- We need to know where the ground is in order to not destroy it
- We need to not be incredibly rigid when we touch the ground
- Force control and compliance is the answer

Structural

- **Steel weldments**
  - **Strong**
  - **Cheap**
  - **We can model them**
  - **We can fab them**

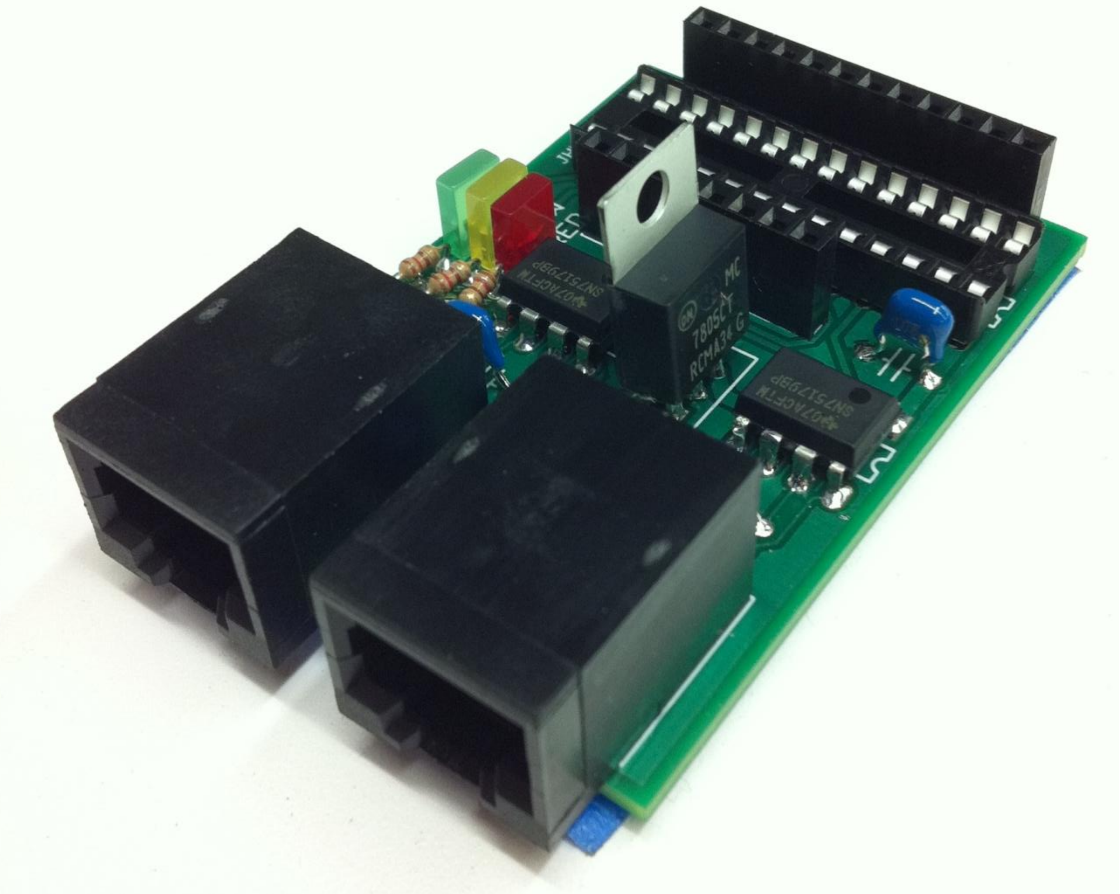


Sensing + Electronics

- At every joint, we need:
  - Position
  - Force
- We have 18 joints spread out over ~20 feet of structure
- We need to read them ~100 times / second

Sensing+Electronics

- **Modular nodes provides extensible digital + analog I/O**



A note about "safety"…

“Safety”

- You are a sack of meat, easily punctured by steel
- Hydraulic systems can channel 100% of their available power to any one piston (flow limits allowing)
  - Nothing like a 50 horsepower punch through the gut
- A pinhole leak in 2,000 psi hydraulic systems can cut your hand off
- Each leg of the full robot will weigh as much as you do
- Propane explodes
- Each cylinder can generate 10,000+ pounds of force

“Safety”

- This robot will not move to you, it will move through you.

How are we building it?

Teams

- Chassis/Powerplant Design Group
- Leg Design Group
- Electronics Group
- Controls Group

Chassis/Powerplant

- Primarily systems and mechanical design
- Layout of cockpit (and passenger?)
- Body shape and structure design
- Engine and pump mounting, sensing and supporting systems
- Trailer attachments

Leg Design

- Primarily mechanical design
- Design of mechanical leg structure
- Selection of hydraulic actuators
- Design of compliance element/force sensor
- Foot system design

Electronics

- Primarily electrical design
- Design of sensing system
- Design of actuator control system
- Implementation of robust, large scale electronics system
- Firmware development

Controls

- Primarily programming/control systems
- Design of inverse kinematic libraries
- Design of several gaits
- Tuning of control loops
- User input design and control

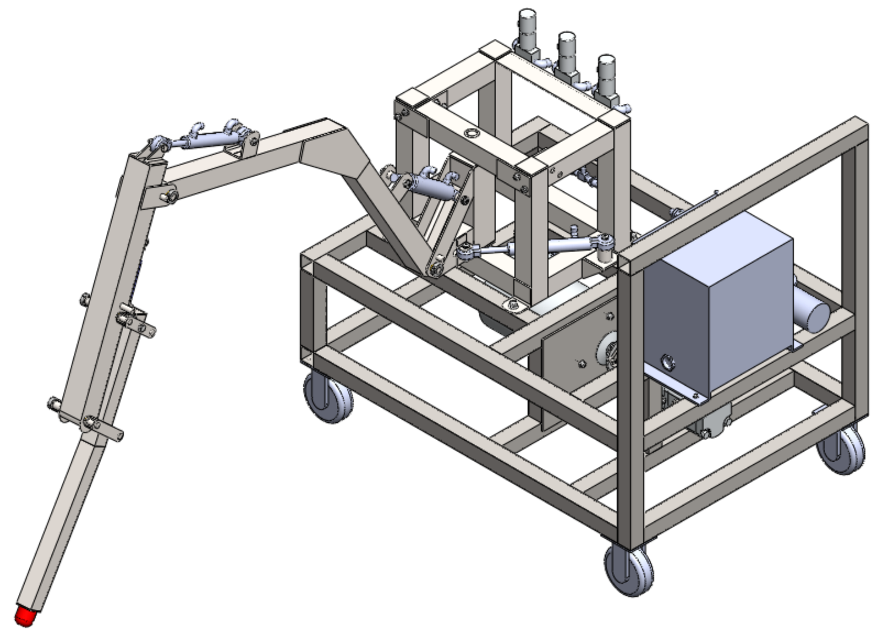
Design Process

Design Exercises

- Leg Cart
  - Mechanical Build
  - Electrical Build
  - Control
- Single-Leg Simulation
- Excavator Research & Design
- HPU Research & Design
- Hexapod Simulation
- Quantitative Mechanical Design

LegCart

- Build a cart on fixed casters with a single hydraulic leg and electric HPU
- Mechanical team gets to assemble hydraulics and work with steel at half-scale
- Electrical team gets to wire feedback devices and central processor
- Controls team gets to figure out how to wrap a control loop and inverse kinematics around hydraulic hardware



Single-Leg Simulation

- Controls team gets a simulator with a leg identical to the LegCart
  - Identical mechanical layout
  - Representative “electrical” inputs
- Gets to prototype inverse kinematics, PID loops, and more in software before moving to hardware

Excavator Research

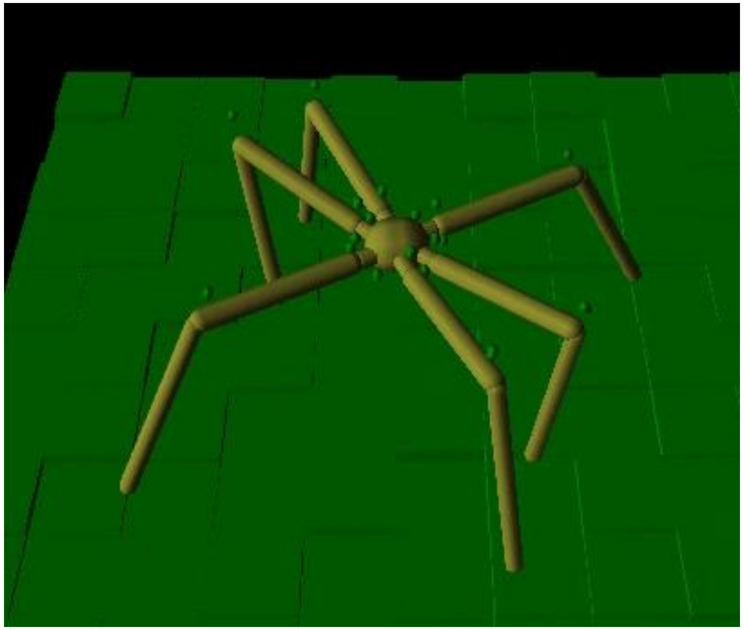
- **Leg design team gets to research how excavators are designed**
- **Excavators are hydraulic and designed to push into the ground; let's figure out why they're designed the way they are, and steal all the good ideas involved**

HPU Research

- Chassis/Powerplant team gets to figure out how hydraulic power units are designed
- Goal for the project is to develop a mobile, propane-powered hydraulic power unit that the rest of the robot attaches to
- Team spends a bunch of time at Blake Courtney's art car shop figuring out how to make the engine go

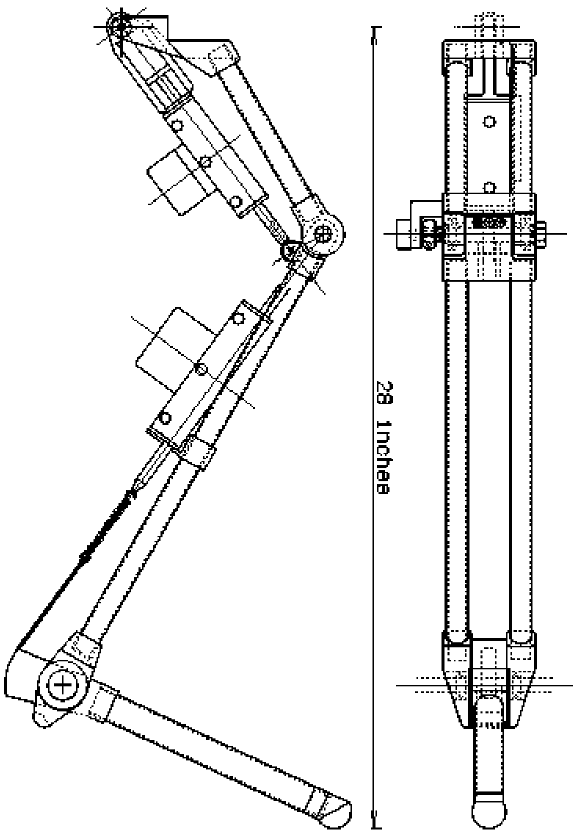
Hexapod Simulation

- Once we have somewhat representative values for weights, link sizes, flow rates, pressures, etc., a representative hexapod simulation is made
- Controls team develops gaits and places actuators in software in order to inform mechanical design



Quantitative Mechanical Design

- Given the results of the simulation, select cylinders, cylinder placements, and leg designs that will create a mechanical plant as close to the simulation requirements as possible



And then we build. Forever.

Or at least until August.

Questions?

Time for hydraulics!