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…
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 Constraints

• 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
• What vehicles produce torque of these magnitudes?
Actuation + Transmission

Excavators!
(Hydraulics)
Actuation + Transmission

- Hydraulics
  - Cheap
  - Available
  - Reliable

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Powerplant + Energy Storage

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