

### Flippers



Resource – Actuation

flippers

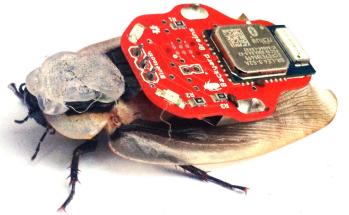
### Vacuum Gripper



Resource – Actuation

vacuum\_gripper

### Cyber-Cockroach



Resource – Actuation

cyber\_cockroach

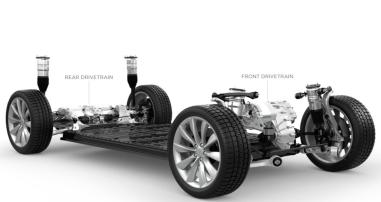
### Weasel ball



Resource – Actuation

weaselball

### Tesla Model X Chassis



Resource – Actuation

model\_x\_chassis

### One segway base



Resource – Actuation

segway\_base

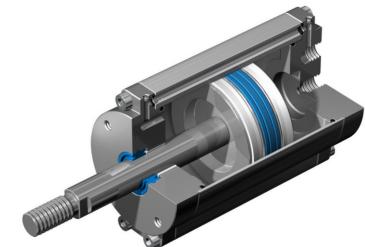
### Loudspeaker



Resource – Actuation

loudspeaker

### Differential Drive



Resource – Actuation

A differential drive robot has two wheels, powered independently. The center of its axle can follow any continuous path in  $\mathbb{R}^2$ .

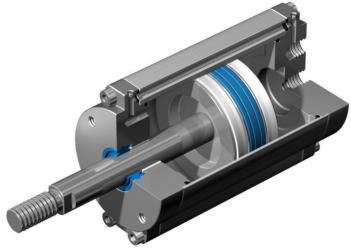
ddr

### Puppetry Wires



Resource – Actuation

puppetry\_wires

**1 RGB LED**

Resource – Actuation

led

**Christmas lights**

Resource – Actuation

christmas\_lights

**Tracks**

Resource – Actuation

tracks

**RC Car Chassis**

Resource – Actuation

rc\_car\_chassis

**Circular Saw**

Resource – Actuation

circular\_saw

**2 Legs**

Resource – Actuation

A basic humanoid leg kit sold by TrossenRobotics.

6359.90 USD 2legs

**One robotic finger**

Resource – Actuation

*"When the finger points to the moon, the student looks at the finger."*

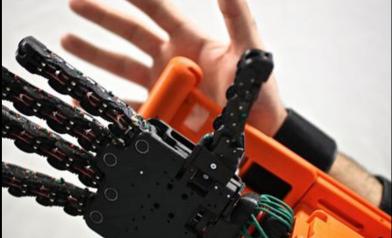
finger1

**DC Motor**

Resource – Actuation

*Have power, will rotate!*

dcmotor

**One robotic hand**

Resource – Actuation

1hand

### Lynxmotion Pan-tilt Kit

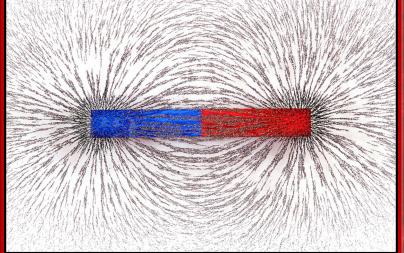


#### Resource – Actuation

A cheap pan-tilt kit made of two HiTec servos (HS-422) and two Lynx-motion servo brackets.

29 USD lynxmotion\_pan\_tilt\_kit

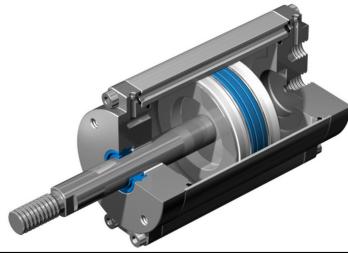
### Magnetic field



#### Resource – Actuation

magnetic\_field

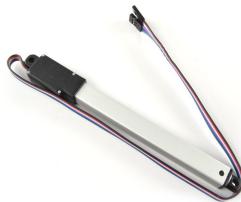
### Five links for a robot snake



#### Resource – Actuation

5\_snake\_links

### Linear Actuator

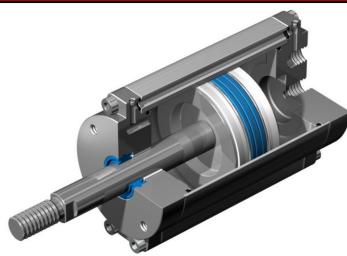


#### Resource – Actuation

Creates motion in a straight line.

linear\_actuator

### Pheromons



#### Resource – Actuation

Artificial pheromones.

pheromons

### Servocity PT-2100 Pan-tilt Kit



#### Resource – Actuation

This professional pan-tilt kit can move a payload of up to 10 kg.

8.5 lbs; 1,199.99 USD servocity\_pt2100\_pan\_tilt\_kit

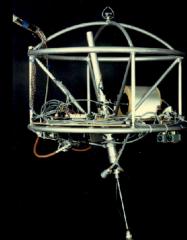
### PR2 Gripper



#### Resource – Actuation

pr2\_gripper

### 3D Hopper



#### Resource – Actuation

The 3D Hopper was created in 1988 by Marc Raibert while at MIT. Successively, Raibert left MIT to found Boston Dynamics.

3D\_hopper

### Balloon



#### Resource – Actuation

balloon

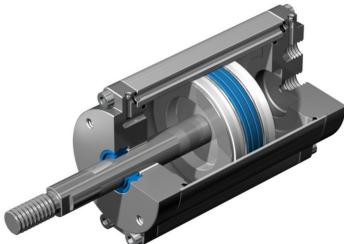
### One tentacle



### Resource – Actuation

1tentacle

### Prismatic Joint

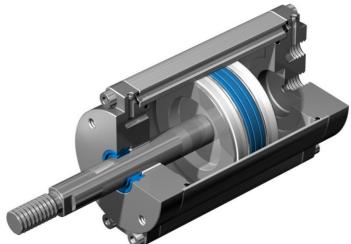


### Resource – Actuation

Provides a one degree of freedom, linear sliding movement between two bodies.

prismatic\_joint

### Wheel



### Resource – Actuation

wheel

### 2 Propellers



### Resource – Actuation

2propellers

### Steerable Needle



### Resource – Actuation

steerable\_needle

### 100 USD (better)



### Resource – Budget

USD 100

100USD

### 1 USD (better)



### Resource – Budget

USD 1

1USD

### USD 10,000



### Resource – Budget

You have 10,000 USD to buy all components.

+ 10000 USD 10KUSD

### Smoke Signals



### Resource – Communication

smoke\_signal

### Communication tether



### Resource – Communication

comm\_tether

### WiFi 802.11 NIC



### Resource – Communication

wifi\_802\_11

### Carrier Pigeon



### Resource – Communication

carrier\_pigeon

### Acoustic Modem



### Resource – Communication

10 bit/s

acoustic\_modem

### The Ansible



### Resource – Communication

You have an infinite communication channel at zero power consumption

ansible

### Random Number Generator



### Resource – Computation

Produces uniformly distributed random real numbers between 0 and 1, rounded to the nearest floating-point number.

rng

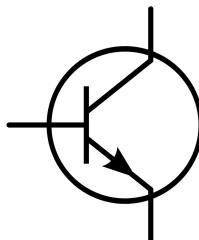
### Arduino Uno



### Resource – Computation

20 USD arduino\_uno

### 1 transistor



### Resource – Computation

Charge will flow between emitter and collector terminals depending on the current in the base, creating a switch or amplifier effect.

1transistor

### NVidia Jetson TK1



### Resource – Computation

199 USD jetson\_tk1

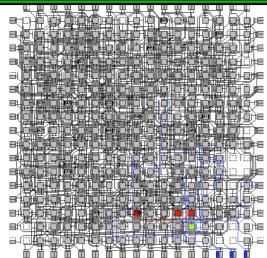
## Raspberry PI 2



### Resource – Computation

35 USD raspberry\_pi\_2

## FPGA



### Resource – Computation

Field Programmable Gate Array

fpga

## Macbook Pro

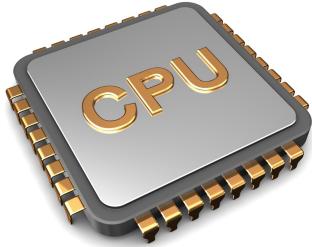


### Resource – Computation

Includes all default software and hardware.

macbook\_pro

## Infinite Computation



### Resource – Computation

You may instantly compute anything for which there is a known algorithm, on any machine.

infinite\_computation

## The Cloud



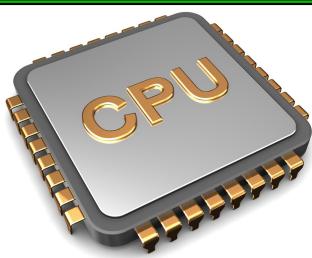
### Resource – Computation

You have infinite computation – but not necessarily infinite bandwidth.

*"Somewhere, over the rainbow!"*

cloud

## 100-state DFA



### Resource – Computation

States and state transition function are user-defined.

100dfa

## TrueNorth Processor



### Resource – Computation

The neuromorphic processor created by IBM.

truenorth

## Oracle



### Resource – Computation

This oracle answers one 1 bit question per second.

oracle

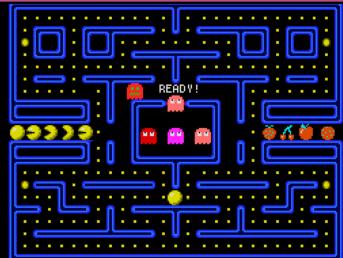
## Underwater



### Environment

underwater

### Pacman's maze



Environment

pacman\_maze

### Lake Michigan



Environment

Did you remember the O-rings?

lake\_michigan

### Intel Lab in Seattle



Environment

intel\_lab

### Mount Etna



Environment

etna

### Deep Space



Environment

deep\_space

### Bat Cave



Environment

batcave

### Mars



Environment

Mars is the only planet completely inhabited by robots.

mars

### Hoth



Environment

hoth

### In the mall



Environment

in\_the\_mall

### The Dagobah Swamps



Environment

dagobah

### The Endor Forest



Environment

endor

### The Bates Motel



Environment

bates\_motel

### Tatooine



Environment

tatooine

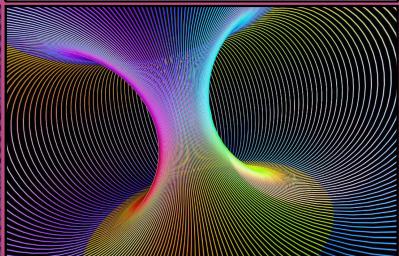
### Ice Rink



Environment

ice\_rink

### Toroidal office space



Environment

torus

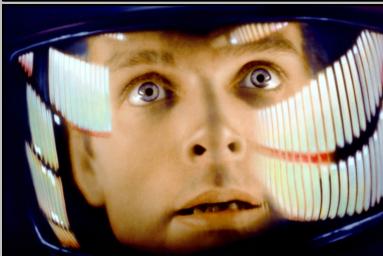
### On a ski slope



Environment

ski\_slope

### Theory of Everything



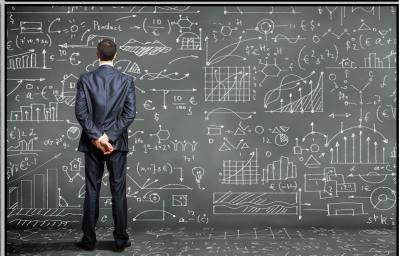
Special

A reviewer can use this card to dismiss the paper as over-reaching.

*The results should be more concrete.*

everything16

### Fundamental Theorem



Special

This card can be played by a reviewer to reject a paper by appealing to authority.

*The Fundamental Theorem of Robotics (Egerstedt, 2001) subsumes all subsequent results.*

fundamental01

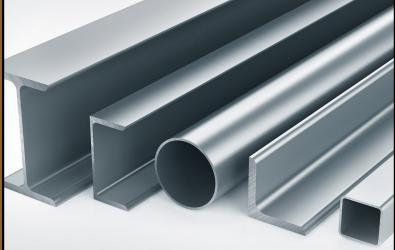
### Color-changing material



Resource – Materials

color\_changing\_material

### All the aluminum you need



Resource – Materials

aluminum

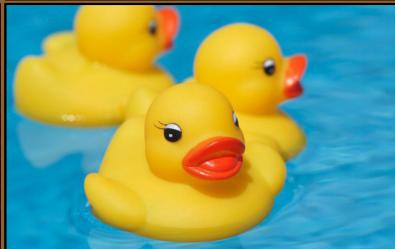
### A bag containing 300 duckies



Resource – Materials

bag\_of\_duckies

### One standard duckie



Resource – Materials

duckie

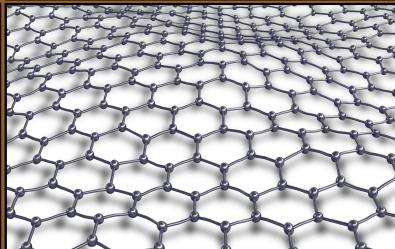
### Shovel



Resource – Materials

shovel

### All the graphene you need



Resource – Materials

graphene

### All the balsa you need



Resource – Materials

balsa

### A giant rubber duckie



Resource – Materials

giant\_rubber\_duckie

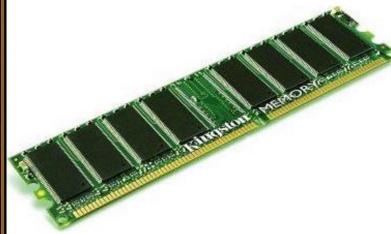
### 640 KB



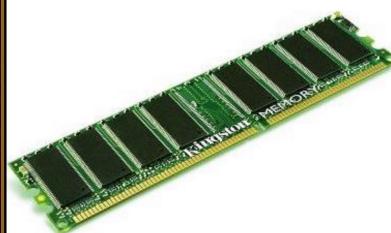
Resource – Memory

640K ought to be enough for anybody.

640KB

**Infinite memory****Resource – Memory**

infinite\_memory

**1 bit****Resource – Memory**

1bit

**10x multiplier** $\times 10$ **Special**

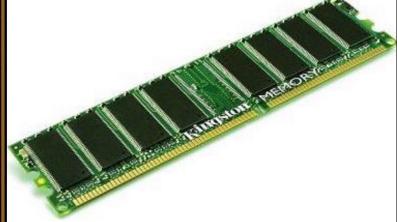
A chosen resource can be multiplied by 10.

mult10

**One pebble****Resource – Memory**

A uniquely identifiable landmark that you can place wherever you want (and pick up again later).

pebble

**Ideal Stack****Resource – Memory**

No stack overflow!

stack

**2x multiplier** $\times 2$ **Special**

A chosen resource can be multiplied by 2.

mult2

**5x multiplier** $\times 5$ **Special**

A chosen resource can be multiplied by 5.

mult5

**Very Dedicated Grad Student****Resource – Collaborator**

Use this resource as you wish.

dedicated\_grad\_student

 **$\infty$  multiplier** $\infty$ **Special**

A chosen resource can be multiplied by  $\infty$ .

multinf

**Steve Lavalle****Resource – Collaborator**

Thanks to an optimal design of the filter, you can *handwave away* all the concerns regarding the computation requirements of the proposed solution.

lavalle

**Friend at IRB committee****Resource – Collaborator**

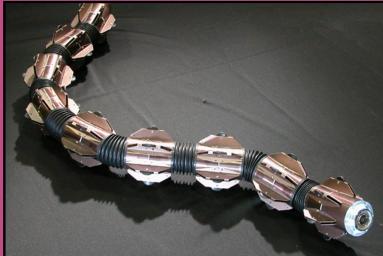
The IRB will approve your project in spite of its questionable ethics. This card is especially useful in conjunction with *Very Dedicated Grad Student*.

irb\_approval

**Titan XIII****Resource – Platform**

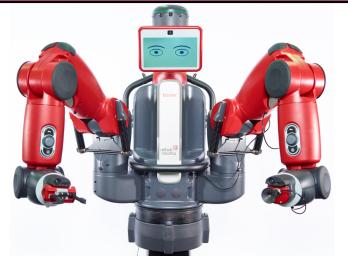
The newest sprawling-type quadruped robot from the Hirose/Fukushima laboratory at Tokyo Institute of Technology.

titanXIII

**ACMR5 Amphibious Snake****Resource – Platform**

Snake robot from the Hirose/Fukushima laboratory at Tokyo Institute of Technology.

ACMR5\_snake

**Baxter****Resource – Platform**

baxter

**KUKA Youbot****Resource – Platform**

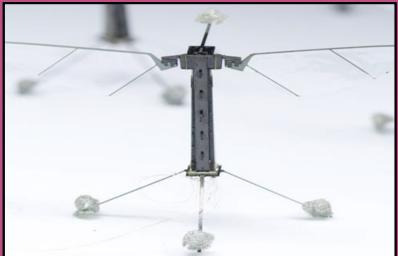
kuka\_youbot

**Gimball****Resource – Platform**

gimball

**R2D2****Resource – Platform**

r2d2

**Robobee****Resource – Platform**

robobee

### Dragon Runner



#### Resource – Platform

A compact remote-controlled robot used by the British army.

20 lbs; 120,000 USD dragon\_runner

### Duckiebot



#### Resource – Platform

duckiebot

### PR2



#### Resource – Platform

pr2

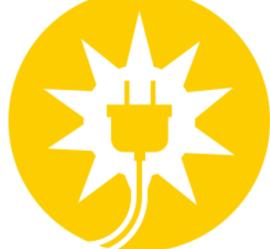
### DJI Phantom 4



#### Resource – Platform

400 USD dji\_phantom\_4

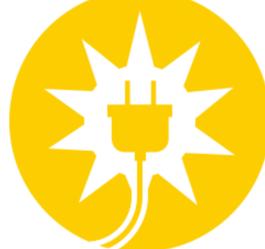
### 1 megawatt



#### Resource – Power

1 MW megawatt

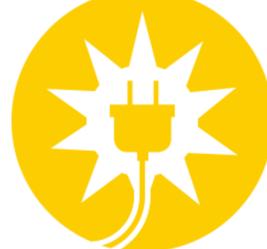
### 100 watt



#### Resource – Power

100 W 100watt

### 1 milliwatt



#### Resource – Power

1 mw milliwatt

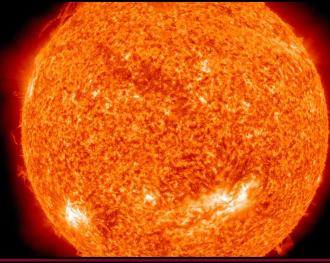
### Rechargeable AAA Battery



### Resource – Power

aaa\_battery

### The power of the sun

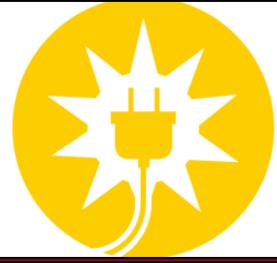


### Resource – Power

You can channel all the power irradiated by the sun into supporting your robotic system.

$3.828 \times 10^{26}$  W the\_power\_of\_the\_sun

### 1 watt



### Resource – Power

1 W watt

### Bitterness



### Rewards

Your negative opinion as a reviewer counts double.

bitterness

### Bitterness



### Rewards

Your negative opinion as a reviewer counts double.

bitterness2

### Military-grade FOG



### Resource – Sensing

The Astrix 1090 is a 3-axis fiber-optic gyroscope produced by Airbus. It is designed to work for >20 years in small satellites.

12 W; 4.2 kg; 100,000 USD astrix\_1090

## GelSight

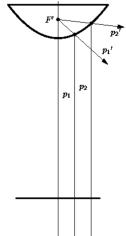


### Resource – Sensing

An image-based tactile sensor that works by sensing the deformation of a thin film in contact with the object.

gelsight

## Parabolic mirror

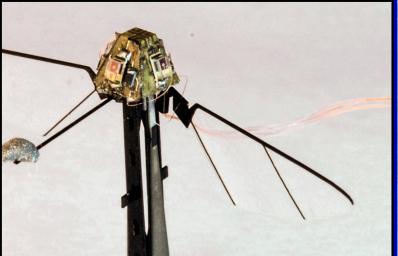


### Resource – Sensing

Turns a camera into an omnidirectional camera.

? W; ? USD parabolic\_mirror

## Artificial Ocelli sensor



### Resource – Sensing

ocelli

## Sick LMS511 Range Finder



### Resource – Sensing

A 2D, 190 deg, range finder with 0.25 deg resolution per ray. The maximum range is 80m.

22 W; 3.7 kg; 7000 USD Sick\_LMS511\_11100\_Lite

## Odour sensor



### Resource – Sensing

odour\_sensor

## CURVACE sensor



2mm

### Resource – Sensing

CURVACE

## Sonar



### Resource – Sensing

sonar

## Cheap IMU



### Resource – Sensing

Uncalibrated accelerometer, gyrometer, and magnetometer.

3.3 V; 9.90 USD cheap\_gyro

## Bump Sensor



### Resource – Sensing

Works by measuring the capacitance of twelve electrode points. When an object comes close to the electrode connector, the measured capacitance changes.

30  $\mu$ A, 3.3V; 7 USD bump\_sensor

## Pressure Sensor



### Resource – Sensing

A pressure to voltage transducer.

? W; 235 USD pressure\_sensor\_PX302

## Thermal imaging camera



### Resource – Sensing

thermal\_imaging\_camera

## Earth GPS Receiver



### Resource – Sensing

Consumer grade, accurate to within a few meters (as long as the robot can see the satellites!)

100 mA, 3.3 V; 25 USD earth\_gps\_receiver

## Compass



### Resource – Sensing

Detects the local magnetic field. Un-powered, requires vision system to read.

0 W; 1 USD compass

## Velodyne HDL-64E



### Resource – Sensing

LIDAR, creates point cloud of distance data.

*With 2.2 million data points per second output rate, the HDL-64 provides all the distance sensing data you will ever need.*

60 W; 29 lbs; 6000 USD velodyne\_HDL\_64E

## Linear Odometer



### Resource – Sensing

? W; ? USD linear\_odometer

## Hokuyo range-finder



### Resource – Sensing

A reliable sensor. Maximum range is 8m.

5 W; 2000 USD hokuyo\_urg

## 1-point Range Finder



### Resource – Sensing

? W; ? USD 1point\_range\_finder

## Kinect



### Resource – Sensing

An RGB camera, depth sensor and multi-array microphone running proprietary software, which provide full-body 3D motion capture, facial recognition and voice recognition capabilities.

99 USD kinect

### Camera



### Resource – Sensing

? W; ? USD camera

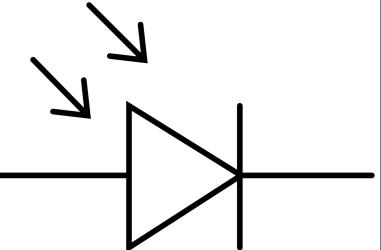
### Microphone



### Resource – Sensing

250  $\mu$ A, 5V; 10 USD microphone

### Photoreceptor



### Resource – Sensing

photodiode

### Dynamic Vision Sensor



### Resource – Sensing

dvs

### Goal posts have moved



### Special

You can change the current goal by changing either the *Task* or the *Environment* card.

*"We must run as fast as we can, just to stay in place. And if you wish to go anywhere you must run twice as fast as that."*

goal\_posts

### 3D printer



### Special

You can 3D print a piece for your robot.

3dprinter

### The Power of Friendship



### Special

Use a card belonging to somebody else.

the\_power\_of\_friendship

### Competitive collaboration



### Special

You can use the cards of another player to create a design. However, if the paper is accepted, only one of you, decided randomly, will get the *Name Recognition* reward.

competitive\_collaboration

### A Russian did it in the 1960s



### Special

The paper under review is rejected.

russian

### Do research!



#### Special

Create a new card using one of the empty cards. Put it randomly in the deck.

do\_research

### Assemble IKEA furniture



#### Task

assemble\_ikea

### Change diaper



#### Task

diaper

### Sort fruits by color



#### Task

sort\_fruits

### Find all Easter Eggs



#### Task

find\_easter\_eggs

### Perform surgery



#### Task

surgery

### Rescue all survivors



#### Task

rescue\_survivors

### Play chess



#### Task

chess

### Track ???



#### Task

track

### Find and disarm an IED



Task

IED\_disposal

1 week



Resource – Time

1 week to perform the task

1week

1 day

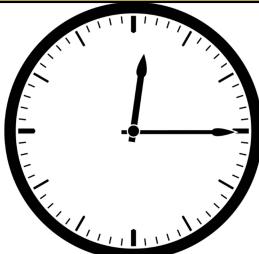


Resource – Time

1 day to perform the task

1day

1 hour

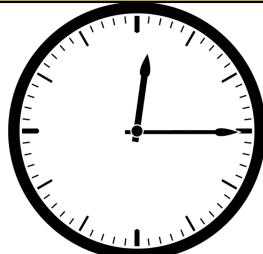


Resource – Time

1 hour to perform the task

1hour

1 year

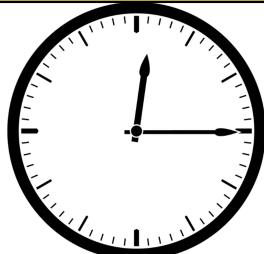


Resource – Time

1 year to perform the task

1year

All the time in the world



Resource – Time

You have all the time in the world to perform the task.

all\_the\_time

Perfect parameter tuning



Resource – Data

perfect\_parameter\_tuning

Infinite training data



Resource – Data

You have infinite training data.

infinite\_data

8000 robot-hours of training data



Resource – Data

8000\_hours

### Lazy graduate student



#### Resource – Data

The lazy graduate student will only collect 2 hours of training data.

lazy\_graduate\_student