Robotics is such a wonderfully diverse field! Think of all the robots you can create by choosing different combinations of sensors, actuators, computing devices, energy sources, behaviors, algorithms, and so on: hardware and software, everything comes together in the field of Robotics.

Given a task, what is the "best" robot to perform it? The cheapest? The one with the highest performance? So many trade-offs exist in this phenomenally large design space.

How can we formalize this co-design problem? Can computers help us? Can we devise automated co-design and co-generation methods?

We created the Robot Design Game to share our excitement about this aspect of Robotics with everybody else. Eventually, this will be a routine problem for an AI to solve, but for now, it is a fun party game for humans.

We hope you have fun playing it, as much as we had creating it! And we'll see you at our workshop to talk about the science behind it.

Andrea, Hadas, Alli, Dylan, and Jason

The Robot Design Game

The game is loosely modeled on the Iron Chef competition. In Iron Chef, participants are given ingredients, and they need to come up with a recipe. In the Robot Design Game, the participants are given *resources* and they need to create a robot design to perform a given *task* in a given *environment*.

The design goal is represented by "task cards" and "environment cards". There are "resource cards" that represent the physical and logical components that the players can use to create a design, such as actuators, sensors, computation devices, and so on.

Each player has two private cards, and there is a pot of "common cards" on the table that can be used by everybody. In this aspect, the game is similar to *Texas Hold'em* poker.

In turn, each player can either pick a card (while discarding one, which becomes a common card), or try to describe a solution for the design problem, based on the components on the cards in hand and on the table.

Rather than having a British chef to judge, the

The "supplementary materials"

Each card has a QR code on its back. The QR code links to a page containing extra information about the card, which we might call the "supplementary materials". These include:

- Technical specifications for the device;
- Videos showing the device in action;
- Links to papers and bibliography references.

Players are encouraged to check out the supplemental materials, if they do not know some of the resources they have available.

If the player tries to use a device plainly beyond its capabilities, the design is deemed unfeasible and automatically rejected. (For fictional devices, there is more leeway for creative interpretation.)

The supplementary materials are contained in a wiki that can be publicly edited. Please help us populate the entries!

Accessibility Another use of the QR code is for accessibility to visually impaired people. The card's page contains a copy of the text shown on the card that can be read by a screen reader.

The rules, in detail

Participants This is a game for 1 dealer, also known as the "associate editor", and $n \geq 2$ players.

The game is the most fun with n between 6 and 8 participants. Fewer players don't give rise to the spontaneous growth of a sense of "community". On the other hand, with many players, rounds can take too long.

Goal The goal of the game is for players to create a robot design using the resource cards. The design is subject to peer review.

One-time setup The following are the instructions for setup of a new game.

1. Make five piles of cards:
   - The **Task** cards.
   - The **Environment** cards.
   - The **Rewards** cards.
   - The **Resource** cards.
   - The blank template cards.
2. Set aside the blank template cards; they are needed only rarely.
3. The associate editor takes the **Rewards** cards and sets them aside, but somewhere ac-

cessible to him/her.

4. The players shuffle and cut the **Task**, the **Environment**, and the **Resource** piles. For the huge **Resource** pile, it is advisable to employ a divide-and-conquer strategy.

At the start of each round This is what happens at the start of each round:

1. The first step is to randomly select a **Task** and an **Environment** card. The associate editor may use any method; for example, having any player choose one card randomly.
2. Together, the chosen **Task** and **Environment** cards define what is the goal for this round. They are placed face up in the center of the table. The other cards from those piles will not be needed for the remainder of this round.
3. The associate editor deals two **Resource** cards face down to each player.
4. The associate editor places one card on the table, face up. That card becomes a common card that anybody can use.

The associate editor decides, possibly randomly, who is the first player to start the game, and then the round proceeds counterclockwise.[1]

Game turn The player has 15 seconds to pick one of two actions:

1. *Submit a design*: the player tries to win the game by proposing a design. This initiates the "design submission phase", detailed below.
2. *Pick up a card*. The player can pick up a card from the top of the deck. Before this happens, the player must discard one of their cards, face-up, onto the table. The discarded card becomes public and is then available for others to use. The player or the associate editor should describe the card to the other players. After picking up, if the player wishes to *submit a design* they must wait until their next turn.

The game proceeds until a player has successfully submitted a design.

[1] There is some asymmetry in the game: the first players have few cards on the table, but they also get the first move advantage; later players, instead, have more cards on the table. At this point, it is not clear who is advantaged. Randomness resolves any doubts.

The design submission phase The player must convince the other players that the task has been solved using the cards in their hand, plus those on the table.

This is the sequence of events:

1. The associate editor asks: "What is the title of the paper?" If the title of the paper is not compelling, the associate editor can reject the paper without review. Otherwise the player proceeds to explain their proposed solution.
2. First, the player must declare which cards in their hand (if any) they wish to use for the design. The cards are put on the table and become common cards.
3. Then, the player must declare which cards (if any) they wish to use from the cards on the table. The associate editor temporarily takes away the other cards on the table for the duration of the next step.
4. The player must then "write" the "paper". The player does this by describing how the proposed solution might solve the current task. All and only the cards that were selected must be used in the design.

Choice of reviewers After the player finishes, it is time for the peer review.

The associate editor selects "reviewers" from the group. The usual number is 3, but it is at the discretion of the associate editor whether to ask for either fewer than or more than 3.

The associate editor can choose the reviewers arbitrarily. The choice can also be random, for example using dice.[2]

Reviews Each reviewer gives a short response to the paper, in the stylistic form of a peer review, raising objections as they see fit, and, of course, commenting on the positive aspects of the proposed design.

It is compulsory for the reviewers to look straight into the eyes of the author while they give their criticism—the review is not valid otherwise.

The author listens in silence and does not answer the criticism at this point; there is a rebuttal phase later.

[2] A great way for old-school players to show off their d20s.

Instant effects during review phase In this phase, a reviewer may play an **Instant Effect** card, following the particular directions on it.

The card is then discarded. If that is the last card in the hand of a reviewer, they get to pick a card from the deck; the invariant is that a person has at least 1 card and at most 2 cards in their hand.

Rebuttal phase Once all the reviews are in, the associate editor may ask the submitter to respond in a rebuttal phase.

There is no counter-rebuttal phase.

The decision Now it's time for the associate editor to make their decision.

The associate editor must take into account the effect of two cards:

1. Any *Bitterness* card held by a reviewer multiplies by two the weight of their negative opinion (there is no positive opinion multiplier).
2. Any *Name Recognition* card held by the player counts as one positive review.

The associate editor makes a final editorial decision regarding the paper.

In case of rejection The player loses the cards in that made up the rejected submission, which now join the common cards on the table. If the player now has zero cards in their hand, then they are dealt a single card.

The author is also awarded a *Bitterness* card.

The round continues with the next player.

In case of acceptance If the paper is accepted, the player wins this round of the game and gains a *Name Recognition* card. This ends the round.

After the round Because the deck is large, we suggest that you avoid reusing the common cards that are on the table. It is rare for a round with 6 people to use more than 40 cards, of which only half are revealed to everybody. Thus, with approximately 200 cards, you can play 10 rounds without seeing the same card twice.

Acknowledgements

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- Dylan Shell (Texas A&M University);

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Major contributors include Ron Fearing (University of California at Berkeley), Ross Knepper (Cornell), Hadas Kress-Gazit (Cornell), and Amy Laviers (University of Illinois at Urbana-Champaign).

For suggestions of new cards, comments, and news, please visit `robot-design.org`.

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ETH zürich

The July 2017 edition of the game was sponsored by the Institute for Dynamic Systems and Control, part of the Department of Mechanical and Process Engineering (D-MAVT), ETH Zürich. A word from our sponsor:

The **Task cards** describe the task which must be completed by the robot.

Change a Diaper

Task

The robot must change a baby's diaper. The baby is required to survive unscathed.

Play Chess

Task

The robot must play chess at a Grand Master level.
You may assume the opponent is not an elephant.

"A player surprised is half beaten."

Perform Surgery

Task

"Meat. They're made out of meat." "Meat?" "There's no doubt about it. We picked up several from different parts of the planet, took them aboard our recon vessels, and probed them all the way through. They're completely meat."

Find All Easter Eggs

Task

The robot must find all Easter eggs hidden in the environment.
Be careful: the eggs are very fragile.

Find and Disarm IED

Task

The robot must safely recognize and disarm an IED in a populated environment.

Waste Sorting

Task

The robot must sort a pile of mixed waste materials into recyclable and non-recyclable.

Rescue Survivors

Task

The robot must find and rescue the survivors of a natural disaster.

Play as a Goalie

Task

The robot must play as a goalie in the World Cup at an acceptable level.

Assemble IKEA Furniture

Task

You may assume that all the tools are included, and you can call technical support in Sweden if you have any questions.
(Picture taken from a paper by Knepper and coauthors presented at ICRA 2013)

Teach an Aqua Gym Class

Task

The robot must teach an aqua gym class. Make sure everybody gives their best!

Medical Evacuation

Task

The robot must evacuate an injured person and transport them as soon as possible to the nearest hospital.

Pipe Inspection

Task

The robot must inspect sewer pipes and report any abnormality in the structure or in inhabitants.

Physical Therapy

Task

The robot must help an injured person in a rehabilitation course to re-obtain normal motor functions.

Wedding Photographer

Task

The robot must shoot pictures of everybody at a wedding.

Supermarket Cashier

Task

The robot must check out and bag the products bought at a supermarket.

Deliver some Jewelry

Task

Deliver valuable jewelry from point A to point B. Beware of thieves!

All that is gold does not glitter,
Not all those who wander are lost;
The old that is strong does not wither,
Deep roots are not reached by the frost.

Sabotage a Military Base

Task

The robot must sabotage a military base of form and appearance adequate to the environment. Try to avoid detection and be prepared for retaliation.

That's no Moon!

Mining

Task

The robot must detect and dig for valuable ore.

A diamond is merely a lump of coal that did well under pressure.

Fix a Leaking Sink

Task

The robot must troubleshoot and repair a leaky sink (without shorting its electronics!). You can assume all replacement sink parts required are available.

Beware of little expenses. A small leak will sink a great ship. —Franklin

Art Restoration

Task

The robot must restore a famous piece of art. The result should be closer to the original than the current state.

Make a Baby Fall Asleep

Task

The robot must make a baby fall asleep. Pharmaceutic solutions are not allowed.

Babysit

Task

The robot must keep a child safe and entertained for 2 hours.

Defuse a Hostage Situation

Task

The robot must talk down a tense situation by noticing behavioral cues from a kidnapper and imparting a sense of calm authority using voice and movement behavior.

Evacuation

Task

The robot must safely evacuate humans in an emergency situation, keeping panic to a minimum.

Patient Care

Task

The robot must find medicine for an elderly patient, conduct an exam of a hurt teenager, or console someone after a traumatic event. The task requires decision analysis as well as bedside manners.

Conduct an Orchestra

Task

Use rhythmically informed movements, which also encode the affect and meaning of the music, to signal to and coordinate among multiple subgroups spatially distributed in the environment.

Mobility on Demand

Task

Create an autonomous mobility-on-demand system for a small city.

Pizza Delivery

Task

The robot must safely transport a pizza - fast enough to keep it warm!

The Deliverator belongs to an elite order, a hallow subcategory. He's got esprit up to here. Right now, he is preparing to carry out his third mission of the night.

Guide the Blind

Task

The robot must help a blind person navigate the environment.

Herding

Task

The robot must herd a flock of animals typical of the given environment.

The **Environment cards** describe the environment in which the robot must perform its task.

Victoria Crater, Mars

Environment

Did you know? Mars is the only planet completely inhabited by robots. You may assume there exist no other Martians.

Under the Sea

Environment

You are in an underwater environment, complete with ocean life forms.

Everything's better
down where it's wetter!

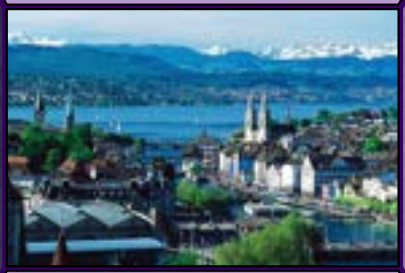
The Bat Cave

Environment

You are in a dark cave, full of bats.

I don't enjoy fear. But I've learned to respect it.

Zürichsee (Lake Zürich)



Environment

You are in Lake Zürich. During the summer, make sure that the robot can avoid the ETH Zürich students who are swimming in the lake and in the Limmat river.

The Forest Moon of Endor

Environment

You are on the Endor moon, which is home to the sentient Ewok, Dulok and Yuzzum species.

The woods are lovely, dark and deep,
But I have promises to keep,
And miles to go before I sleep.

Echo Base, Hoth

Environment

You are on the Hoth planet, a planet covered in ice. The temperature may drop to -60 °C at night.

I think I know enough of hate
To say that for destruction ice
Is also great
And would suffice.

Mount Etna

Environment

You are on Mount Etna, an active volcano in Sicily.
Beware, the floor is lava!

Intel Lab, Seattle

Environment

You are at the Intel laboratories in Seattle. You may assume that the robot has a perfect map of this environment, constructed using dozens of different SLAM methods.

The Bates Motel

Environment

You are in a large motel in the company of one unhinged inhabitant.

It's not like my mother is a maniac or a raving thing. She just goes a little mad sometimes. We all go a little mad sometimes. Haven't you?

The Dagobah Swamps

Environment

You are on Dagobah, a swampy planet, home to creatures such as bogwings, dragonsnakes, and swamp slugs.

I met him in a swamp down in Dagobah, where it bubbles all the time like a giant carbonated soda.

Deep Space

Environment

You are floating in near-vacuum and near-zero-gravity.

If you gaze long into an abyss, the abyss also gazes into you.

Arrakis (Dune)

Environment

You are on the desert planet Arrakis, also known as "Dune".
Look out for sandworms!

In the desert, the line between life and death is sharp and quick.

Ice Rink

Environment

You are in an ice rink, populated by adults and children.

There's an old Wayne Gretzky quote that I love. – Steve Jobs

Springtime Mountain

Environment

It is a sunny Spring day in the mountains near Zürich.

Moria

Environment

You are inside Moria, a vast network of dark tunnels, chambers and mines.

The dwarves delved too greedily and too deep. You know what they awoke in the darkness of Khazad-dum... shadow and flame.

Stata Center

Environment

You are in the Stata Center, building 32 on the MIT campus.
("Stata" rhymes with "data".)
You may assume only the 3D projection of this 5-dimensional structure is relevant to the task.

Times Square

Environment

You are in Times Square during New Year's eve, in a dense crowd full of ecstatic party-goers.
Make sure to find someone for a kiss at midnight!

Grandmother's House

Environment

You are visiting your nana.
Don't be too loud and don't run in the house! Touch things gently!
Make sure to say "please" and "thank you", and, for heaven's sake, don't make a mess!

Suburban Cul-de-sac

Environment

You are in the suburbs.
Keep up with the Jones's and don't start rumors in the neighborhood while navigating this American trope.

The future pre-decided
detached and subdivided

Zermatt ski resort

Environment

You are at the Zermatt ski resort, under the Matterhorn peak.
This is the place chosen for the annual ski trip for the Institute of Dynamic Systems and Control at ETH Zürich.

Not Kansas

Environment

Where are you? It's unclear, but it is definitely not Kansas.
The person to the right of the dealer chooses what is the environment for this round. They should include a description of weather, flora, and fauna, if present.

Red October

Environment

You are in the tight quarters of a submarine, in the company of Sean Connery.

The **Actuation resource cards** describe the actuators available for the robot design.

An actuator is a physical device with which the robot can change something in the world.

DC Motor

Actuation

This DC motor (of any size you like) is controlled in velocity and does not have any position sensors.

"There are no rules here, we're just trying to accomplish something."
– Thomas Edison

Servo Motor

Actuation

This servo motor can be controlled in position and has an accuracy of about 0.1 deg.

Cheap Pan-Tilt Kit

Actuation

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

Do you see over yonder, friend Sancho, thirty or forty hulking giants? I intend to do battle with them and slay them.

High-Quality Pan-Tilt Kit

Actuation

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

'Take care, sir,' cried Sancho. 'Those over there are not giants but windmills.'

Linear Actuator

Actuation

This linear actuator moves in a straight line for a maximum extension of 30 cm.

Straight down the crooked lane, and all round the square.

Finger

Actuation

A single finger, with three hinged joints.

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

Robot Hand

Actuation

A five fingered robot hand. Warning: it will lose grip on objects if jostled roughly, such as when robot is moving over rough terrain.

With one hand he put a penny in the urn of poverty, and with the other took a shilling out.

Tentacle

Actuation

This tentacle can grasp smooth objects reliably with suction cups, but struggles with rough objects.

Talent without discipline is like an octopus on roller skates.

Legs

Actuation

A pair of humanoid legs.

A traveller at Sparta, standing long upon one leg, said to a Lacedæmonian, 'I do not believe you can do as much.' 'True,' said he, 'but every goose can.'

Segway Base

Actuation

This Segway base comes with a battery, and sensing and computation that can only be used for self-balancing. The maximum speed is 20 km/hr.

Life is like riding a bicycle. To keep your balance, you must keep moving.

Tracks

Actuation

A pair of tracks, good for moving over rough terrain.

One woe doth tread upon another's heel.

Differential Drive

Actuation

A platform with two independently-powered wheels.

Change does not roll in on the wheels of inevitability, but comes through continuous struggle.

RC Car Chassis

Actuation

This small toy RC car includes frame, engine, drivetrain, and wheels.

I would have nobody to control me; I would be absolute: and who but I?

Tesla Model X Chassis

Actuation

A "rolling chassis" with frame, engine, drivetrain, and wheels.

Today's scientists … wander off through equation after equation, and eventually build a structure which has no relation to reality.

Weasel Ball

Actuation

The weasel ball is an uncontrollable, sensorless, motorized ball. Dynamics are highly nonlinear: it rolls and bounces off obstacles unpredictably.

Methinks it is like a weasel.

Flippers

Actuation

These stiff rubber flippers come with a motor for producing the flipping motion.

'The time has come,' the walrus said, 'to talk of many things."

Weather Balloon

Actuation

This is a large weather balloon, with a payload of 15 kg.

Would you like to ride in my beautiful balloon?

Vacuum Gripper

Actuation

This vacuum gripper generates a vacuum equivalent to 25 kg of vertical lift.

Where the bee sucks, there suck I; In a cowslip's bell I lie.

Steerable Needle

Actuation

A flexible needle capable of following curved paths through soft tissue.

If you don't like what you're doing, you can always pick up your needle and move to another groove.

Cyber-Cockroach

Actuation

A biological cockroach with implants for computer control.

Any foolish boy can stamp on a beetle, but all the professors in the world cannot make a beetle.

Puppetry Wires

Actuation

These puppetry wires can be attached to anything and used to control it from above.

I know what I look like—a weird, sad clown puppet. I'm fine with that.

Propellers

Actuation

A pair of propellers: they convert rotation to thrust.

If the young person … has poetry in him or her, to offer them help is like offering a propeller to a bird.

Pheromones

Actuation

An emitter of artificial pheromones.

How full and rich a world theirs to inhabit is—Sweet scent of grass and bloom.

RGB LED

Actuation

A three-color LED with independent control of each color.

The rainbow comes and goes, And lovely is the rose.

Christmas Lights

Actuation

A 50 foot string of blinking lights.

Not a creature was stirring, not even a mouse.

Speaker

Actuation

This speaker converts electrical impulses into loud sounds.

A sound so fine, there's nothing lives twixt it and silence.

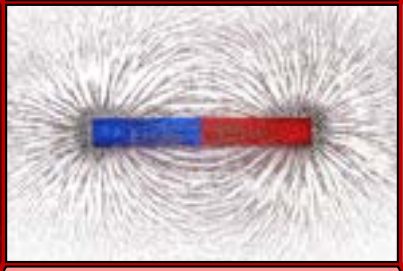
Circular Saw

Actuation

A spinning blade, capable of cutting through wood and similar materials, but cannot cut through metal.

I don't think so, Tim.

Bar Magnet



Actuation

An 8 cm long bar magnet, strong enough to stick to a fridge (0.01 Tesla)

Are you a firm believer in miracles?

Quadrotor

Actuation

This quadrotor frame contains a battery and the motors, but no sensors or computation resources.

Fixed Wing Frame

Actuation

This fixed wing frame contains a battery and the motors, but no sensors or computation resources.

Rope and Winch

Actuation

The rope extends up to a maximum of 100 m, and the maximum load is 50 kg.

Bubble Machine

Actuation

An unlimited supply of bubbles!

Bubbles floating all around
Bubbles fat and bubbles round
Bubbles on my toes and nose
Blow a bubble, up it goes!

Water Gun

Actuation

This water gun has a 1 liter reservoir, and can spray water up to a distance of 10 m.

Dust Removal Tool

Actuation

The Dust Removal Tool (DRT) is a motorized, wire-bristle brush on the turret at the end of Curiosity's arm. The DRT was first used on a rock target named *Ekwir_1* on January 6, 2013. Honeybee Robotics built the DRT.

Lidar Cleaning System

Actuation

This apparatus can be used to make sure that the sensors remain clean in the face of unexpected avian-produced occlusions.

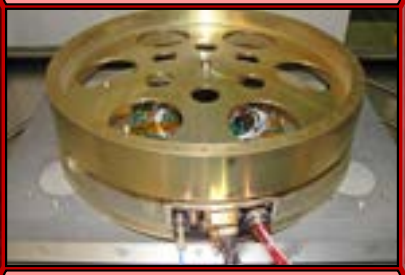
(Google / Waymo)

Rover Wheels

Actuation

These wheels are appropriate for Mars, the Moon, and other sandy and rocky environments. They are rated for a maximum speed of 0.05 m/s.

Reaction Wheel



Actuation

Great choice to turn around your satellites.

Four Reaction Wheels

Actuation

Four reaction wheels allow to arbitrarely orient a satellite.

Parachute

Actuation

Use a parachute to slow any falling object to a safe landing speed.

Slow down and enjoy life. It's not only the scenery you miss by going too fast; you also miss the sense of where you are going and why.
— Eddie Cantor

Hydrazine Thruster

Actuation

Do you need a boost? This thruster provides up to 20 s of additional thrust.

If you start me up / If you start me up I'll never stop.

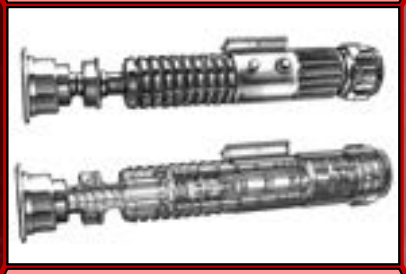
High-intensity Laser

Actuation

A class 4 laser that may ignite combustible materials.

Let there be light—perfectly coherent light.

Lightsaber



Actuation

An elegant weapon, for a more civilized age.

Gecko Feet

Actuation

Just like *Stickybot* developed by the Cutkosky group at Stanford, the robot can stick to vertical walls using dry adesion.

Flagella

Actuation

The robot can use microscopic flagella for locomotion, just like bacteria.

Artificial robotic flagella guided by magnetic fields have been studied by the Nelson lab at ETH Zürich.

Snail Foot

Actuation

This biomimetic snail foot can be used for locomotion and leaves behind a trail of biomimetic snail slime. The snail foot cannot be used in arid environments.

Mind Control

Actuation

The robot is able to control the thoughts and actions of any animal or human.

The **Sensing resource cards** describe the sensing modalities available for the robot design.

Compass

Sensing

The robot can detect the orientation of the local magnetic field.

Thermometer

Sensing

The robot can detect the local temperature.

Barometer

Sensing

The robot can detect the local air pressure.

Microphone

Sensing

The robot can listen to environmental sounds.

Wheel Odometer

Sensing

A wheeled robot can measure the distance travelled.

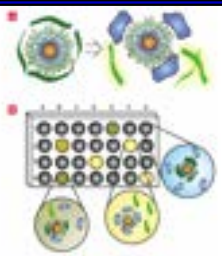
Pressure Sensor

Sensing

A pressure to voltage transducer.

It's the terror of knowing what the world is about...

Olfactory Sensor



Sensing

The robot can sense any scent that an animal can.

Do you smell it? That smell. A kind of smelly smell. The smelly smell that smells... smelly. – Mr. Krabs

Cheap IMU

Sensing

An uncalibrated accelerometer, gyrometer, and magnetometer.

Turning and turning in the widening gyre
The falcon cannot hear the falconer

Military-grade Gyroscope

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. Assume negligible error in the sensor readings.

1-point Range Finder

Sensing

The robot can measure the distance to the nearest obstacle in one direction.

Do you think the prisoners would imagine that the speaker were anyone other than the shadow passing in front of them?

GelSight

Sensing

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

Sonar

Sensing

An active (requires power) sonar system. Maximum range of 7 meters in air.

Bump Sensor

Sensing

This bump sensor works by measuring the capacitance of twelve electrode points. When an object comes close to the electrode connector, the measured capacitance changes.

Hokuyo Range-Finder

Sensing

The maximum range is 8 m, the accuracy is about 3 mm, and the resolution is 1 ray/deg.

Kinect

Sensing

The Kinect is 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.

Sick LMS511 Range Finder

Sensing

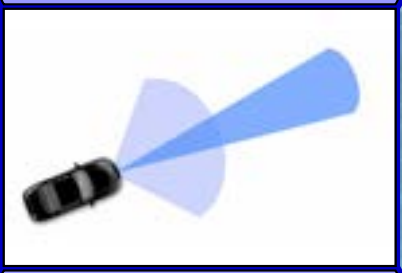
A 2D, 190 deg range finder with 0.25 deg resolution per ray. The maximum range is 80 m.

Velodyne HDL-64E

Sensing

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

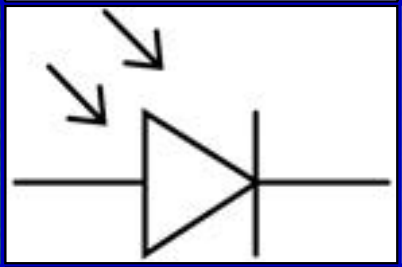
Automotive-Grade Radar



Sensing

This automotive-grade radar provides reliable detection up to 80 m with a field of view of 25 degrees.

Photodiode



Sensing

A photodiode is a semiconductor device that converts light into current.

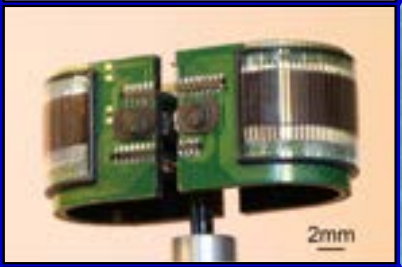
Artificial Ocelli Sensor

Sensing

This artificial ocelli sensor, inspired by the fly biology, is composed by four defocused photoreceptors that can provide enough information to estimate and control the platform attitude.

(Fuller, Harvard/UW)

CURVACE



Sensing

This "Curved Artificial Compound Eye" is inspired by the the fly's ommatidia and provides a 1-dimensional line of pixels over 360 deg. It is 2.2 cm^3 large, and weighs 1.75 g.

(Floreano group, EPFL)

Consumer-grade Camera

Sensing

A two-megapixel consumer-grade digital camera.

You don't take a photograph, you make it. – Ansel Adams

Industrial-grade Camera

Sensing

A 15-megapixel industrial-grade digital camera.

Military-grade Camera

Sensing

This military-grade camera can resolve details at a resolution of 1 cm from low-Earth orbit.

Dynamic Vision Sensor

Sensing

The DVS is an event-based vision sensor that provides an asynchronous stream of events with a 1 μs resolution corresponding to a change in intensity in each pixel.

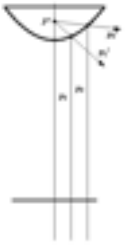
(Delbruck group, University of Zürich / ETH Zürich)

Thermal Imaging Camera

Sensing

This thermal imaging camera arovides a colorized image or video of thermal measurements between -40 and 2000 °C.

Parabolic Mirror



Sensing

Using a parabolic mirror, you can turn a camera into an omnidirectional camera.

Beacon System

Sensing

You can place 3 beacons anywhere and be able to triangulate the robot's position in a range of about 10 km with a resolution of 2 m.

Motion Capture System

Sensing

You can observe a very precise state estimate of the robot configuration in an area of 20 m × 20 m × 20 m.

Earth GPS Receiver

Sensing

This consumer-grade GPS receiver is accurate to within a few meters, as long as the robot can see the satellites.

Eye Tracking

Sensing

Detect the point of gaze of a human.

Do not avert your eyes.
It is important
that you see this.
It is important that you feel this. – Kamand Kojouri

Heart Rate Monitor

Sensing

This device can monitor the heart rate of a human. It works at a maximum distance of 1 m.

Electrolocation

Sensing

Your robot can sense weak electric fields, using the same principle as what is used by the elephantnose fish (*Gnathonemus petersii*).

Mind Reading

Sensing

The robot may read, but not control, the conscious and unconscious mind of any animal or human.

Omniscience

Sensing

The robot can see everything everywhere.

Every move you make
Every vow you break
Every smile you fake
Every claim you stake
I'll be watching you.

The **Energetics resource cards** describe power sources available for the robot design.

For the cards that provide power, you can choose to have available such power in the form that you wish (e.g. mechanical power, electrical power).

1 Microwatt

Energetics

You have available 1 μW of power, which is approximately the power consumption of a mechanical wristwatch.

1 Milliwatt

Energetics

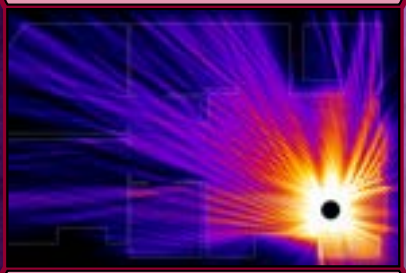
You have available 1 mW of power, which is roughly equivalent to the power consumption of a honeybee in flight.

50 Milliwatts

Energetics

You have available 50 mW of power, which is a approximately the power consumption of a bee hummingbird (*Mellisuga helenae*), the world's smallest bird, with an average mass of 2 g.

100 Milliwatts



Energetics

You have available 100 mW of power, which is approximately the transmission power used by a WiFi antenna.

1 Watt

Energetics

You have available 1 W of power, which is roughly equivalent to what could be produced by a hamster on a wheel.

10 Watts

Energetics

You have available 10 W of power. This is the amount of power consumed by a bright LED bulb.

100 Watts

Energetics

You have available 100 W of power. This is equivalent to the average power consumption of a human with a sedentary lifestyle, or the amount of power used by a very bright incandescent bulb.

1 Horsepower (746 W)

Energetics

You have available 1 hp (746 W) of power.

1 Kilowatt

Energetics

You have available 1 KW of power, which is approximately equivalent to the peak power output of a top athlete during a short burst, or the heat generated by a domestic kettle.

1 Megawatt

Energetics

You have available 1 MW of power, which is roughly equivalent to what is produced by a 100 m $\times$ 100 m solar panels installation.

1 Gigawatt

Energetics

You have available 1 GW of power – which is about half of what the Hoover dam can produce.

The Power of the Sun

Energetics

You can channel all the power radiated by the sun into supporting your robotic system. This is approximately 3.828×10^{26} W.

With great power comes great responsibility.

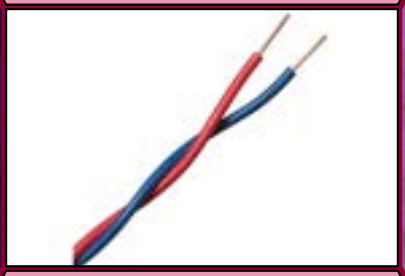
Solar Panels

Energetics

You can use solar panels in your robot. Assume 20% efficiency: a cell of 1 m^2 will produce 200 W on a sunny day in Boston.

Here comes the sun, and I say — It's all right.

Power Tether



Energetics

A 1 km long tether supplying as much power as you need (within reason).

4 AA Batteries

Energetics

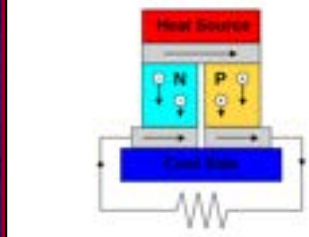
Four AA rechargeable 1.5 V Li-ion batteries. Each battery provides a capacity of 1700 mAh.

Car Battery

Energetics

This 10 kg battery provides 40 Ah at 12 V.

Thermocouple



Energetics

This thermocouple can be used to produce electrical current given a temperature difference.

Plutonium Pellet

Energetics

One pellet of Pu-238, a powerful alpha emitter. Very dangerous for humans to handle.

Plutonium is the darling and the demon of the nuclear age.

RITEG

Energetics

Radio-Isotope Thermo-Electric Generators (RITEGs) run on Plutonium. They are used on satellites and extraplanetary rovers, and they will keep any room comfortably warm.

A Can of Gasoline

Energetics

This is a highly flammable 15 liters can of gasoline.

Air Tank

Energetics

A 20 gallon tank of pressurized air at 150 psi.

I can feel it coming
in the air tonight
And I've been waiting
for this moment
for all my life.

Artificial Stomach

Energetics

The robot can digest organic matter to extract energy.
Assume the diet and energy produced is comparable to the metabolism of a cow.

Photosynthesis

Energetics

The robot can use sunlight to synthesize energy from carbon dioxide and water. Assume 1% efficiency.

"Until man duplicates a blade of grass, nature can laugh at his so-called scientific knowledge." – Thomas Edison

Chemosynthesis

Energetics

The robot can generate energy from carbon-containing molecules (carbon dioxide or methane) using the oxidation of inorganic compounds (hydrogen gas, hydrogen sulfide) or methane.

Mr. Fusion Home Reactor

Energetics

This device can convert 200 g of assorted trash into enough energy to power a car through a time jump.

Dance All Night Long

Energetics

No one knows where this energy comes from, but, assuming the environment contains good vibes, the robot will find power to operate until the wee hours of the morning.

The **Computation resource cards** describe the computation substrate for the robot and certain specific algorithmic capabilities.

Remember that the more computation you use, the more power you need to provide.

One Transistor

Computation

The complexity for minimum component costs has increased at a rate of roughly a factor of two per year. Certainly over the short term this rate can be expected to continue, if not to increase.

100-State DFA

Computation

A deterministic finite automaton (DFA) with 100 states. The states and state transition function are user-defined.

We must accept finite disappointment, but never lose infinite hope.

Arduino Uno

Computation

A microcontroller with a USB port, 14 digital pins, and 6 analog pins.

"I have always loved to begin with the facts, to observe them, to walk in the light of experiment and demonstrate as much as possible, and to discuss the results."

Raspberry PI 3

Computation

This device has 4 USB ports, HDMI, WiFi, Bluetooth, a camera interface, a micro SD card slot. It comes installed with a Linux distribution of your choice.

I was working part time in a five-and-dime; My boss was Mr. McGee.

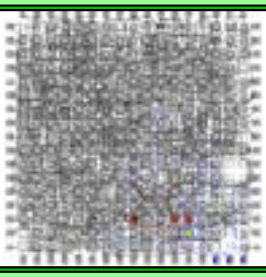
NVidia Jetson TK1

Computation

The NVidia Jetson is a complete computer that includes a GPU with 192 CUDA cores.

Eep Opp Ork! Ah ah! Get in the capsule, baby. We are blasting off.

FPGA



Computation

A Field Programmable Gate Array (FPGA) is a reprogrammable application-specific circuit that can perform parallel computations.

Though wisdom wake, suspicion sleeps at wisdom's gate.

Macbook Pro

Computation

This laptop includes all default software and hardware.

Most people have no concept of how an automatic transmission works, yet they know how to drive a car. … You don't have to understand any of this stuff to use Macintosh.

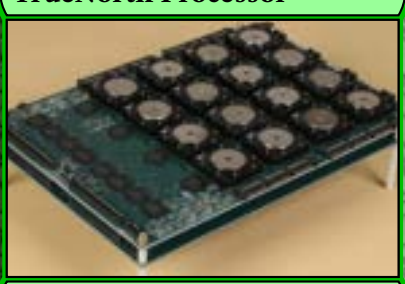
Tensor Processing Unit

Computation

An application-specific integrated circuit (ASIC) developed by Google specifically for deep learning.

I see the eigenvalue in thine eye
I hear the tender tensor in thy sigh
– Love and Tensors, Stanislaw Lem

TrueNorth Processor



Computation

The neuromorphic processor created by IBM, simulating just over a million "neurons".

No one ever got fired for buying IBM.

Human Operator

Computation

You can include a local or remote operator as part of the design.
You must ensure that a local operator can survive the environment, and that a remote operator can communicate with the robot.

The Cloud

Computation

Using the cloud, the robot has effectively infinite computation (but not infinite bandwidth).

"Somewhere, over the rainbow!"

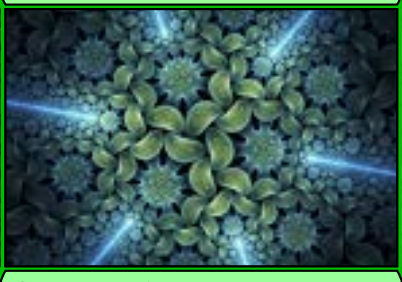
Oracle

Computation

The Oracle will answer a single one-bit question of your choice per second.

I am Sir Oracle, And when I ope my lips, let no dog bark!

Infinite Computation

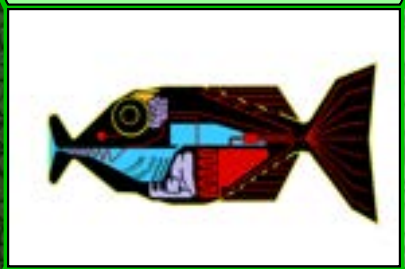


Computation

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

Infinite riches in a little room.

Babelfish



Computation

A Babelfish can translate among all languages, human, animal, and alien. A ROS driver is included.

The Babel fish is small, yellow, leech-like, and probably the oddest thing in the Universe.

Theory of Mind

Computation

There is enough computation power for the robot to have a complete theory of mind (the ability to attribute mental states to oneself and others).

Pose Classification

Computation

The robot is able to label human poses with context-specific classifications.

Movement Classification

Computation

Label human movements with context-specific classifications. Be careful in the interpretation: Nest smoke detectors used a hand waving in the air to turn themselves off—but people also wave their hands when they need help or are on fire!

Intent Detector

Computation

The robot can understand a person's intent, given observations of their behavior.
Note: People are complicated; results may vary.

Affect Detector

Computation

Given a camera image of a person's face, the robot can perform *affect detection* (classifying the human's emotion) with about 80% accuracy.

The **Communication resource cards** describe methods and devices with which the robot can communicate with its team members, operators, or subjects.

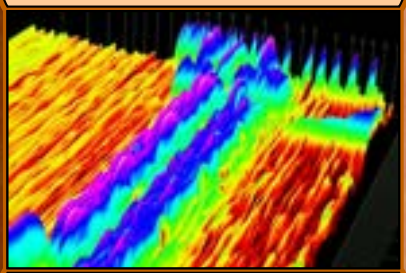
Acoustic Modem

Communication

This acoustic modem can be used to communicate underwater, at around 10 bit/s at a distance of 1 km, on a good day.

I'm not asking much. … What I want from you is your voice.

56 kbps modem



Communication

Party like it's 1995 with this 56 kbps modem. The robot has available a 7 KB/s downlink, 3 KB/s uplink channel.

4G LTE Link

Communication

The robot has available a 5 MB/s downlink, 3 MB/s uplink channel.

Satellite Link

Communication

The robot can use a satellite channel with 100 MB/s downlink and 100 KB/s uplink.

"We have abolished space here on the little Earth; we can never abolish the space that yawns between the stars."
– Arthur C. Clarke

WiFi

Communication

A network card compatible with the IEEE 802.11ad standard.

I sincerely doubt that the guy who sells socks by the overpass is providing high-speed Internet to the community.

Communication Tether

Communication

A cable, with gigabit ethernet capacity, connected to a base station.

Nae man can tether time or tide.

Trumpet

Communication

The robot can communicate using trumpet sounds.

Jazz is the big brother of revolution. Revolution follows it around.
– Miles Davis

Beat Box

Communication

The robot can communicate using any rhythm found in an extensive library of human and animal music.

Voice Synthetizer

Communication

This voice synthetizer can be used to play human speech of all languages and accents.

Stench Gas

Communication

In the underground mining industry, *ethanethiol* or *ethyl mercaptan* is referred to as "stench gas". The gas is released into mine ventilation systems to alert mine workers during an emergency.

Smoke Signals

Communication

This is a perfectly respectable form of visual communication over long distance; it can be used to transmit news, signal danger, or gather agents to a common area.

There is no fire without some smoke.

Carrier Pigeon

Communication

Avian communication channel as specified by RFC 1149.

Every time I feel alone; And slightly blue; That's when I begin to think; It's what I'd like to start to do.

The Ansible

Communication

The Ansible provides infinite bandwidth at zero latency.

You remember the ansible, the machine I showed you in the ship, which can speak instantly to other worlds, with no loss of years—it was that that they were after, I expect.

Weak Ansible

Communication

The "weak" ansible is a channel with infinite bandwidth, zero power consumption, but a latency of 1 minute.

A minute seems like a lifetime, baby, when I feel this way...

The **Data resource cards** describe data resources available for the robot design.

Infinite Training Data

Data

You may assume to have infinite training data.

Perfect Maps

Data

You may assume to have perfect maps for the environment.

(Nokia HERE maps)

The **Form resource cards** describe additional properties of the form of the robot.

These could be either static appearance or behavioral properties.

Effort - Action Drive

Form

The robot's motions gain any expressive qualities from the Laban/Bartenieff Movement System's Basic Effort Actions, including *float*, *punch*, *glide*, *slash*, *dab*, *wring*, *flick*, and *press*. For example, *float* to carry an egg; *slash* to show anger.

Character Development

Form

A Pixar animator is employed to construct a character around your platform. They give it personality traits (through distinct movement patterns and quirks) that inspire user acceptance and facilitate communication with humans.

Chameleon Skin

Form

With this chameleon skin, the robot can choose to have the color and texture of the environment around it.

Red Nose and Glasses

Form

Sometimes this is the best thing you could wear.

Artificial Fur

Form

The robot will feel furry to the touch.

Artificial Skin

Form

The robot will feel warm and soft to the touch.

Evil Appearance

Form

The robot will appear evil.

Angelic Appearance

Form

The robot will appear angelic.

Three Standard Duckies

Form

Use these three standard duckies to improve the cuteness of your platform, or in another creative way.

Giant Rubber Duckie

Form

Use this giant rubber duckie for the tasks that require both cuteness and intimidation.

Aesthetics

Form

The robot appears beautiful.
Note: Beauty is in the eye of the beholder. Successful users of this card should define their aesthetic (n.) first.

Anthropomorphism

Form

Make anything look more human. This is not just about making things cute; you will likely be able to take advantage of conventions of human movement more easily. Hint: Start with bilateral symmetry and then add a “face”.

Blast From The Past

Form

The robot can take on the style, manners, and lingo from any time period.

The **Collaborator cards** describe the *human resources* available to the robot.

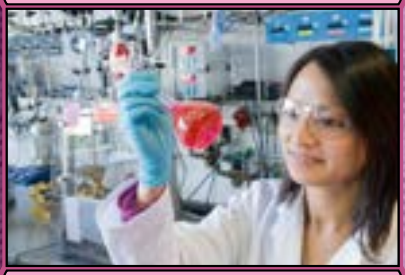
Remember, science is a collective enterprise!

Friend on IRB Committee

Collaborator

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

Very Dedicated Grad Student



Collaborator

Genius is one percent inspiration, ninety nine percent perspiration.

Lazy Graduate Student

Collaborator

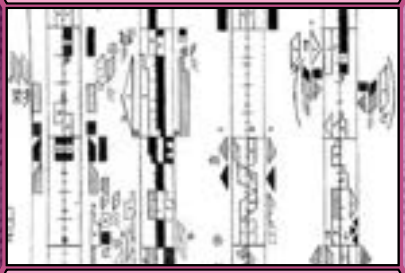
Procrastination is not the same thing as laziness. Laziness is when you don't want to do anything. Procrastination is when you don't want to do the one thing you really ought to be doing.

Certified Movement Analyst

Collaborator

Work with an expert in the Laban/Bartenieff Movement System to understand the mechanisms through which humans in the environment make meaning out of movement. If you want your robot to fit in, this person is a great resource!

Labanotation Scorer



Collaborator

Work with a Labanotation expert to record human movement patterns as a score. This context-specific segmentation of motion aids in parsing or creating meaning from complex movement.

Cyber Lawyer

Collaborator

You can use the help of a cyber lawyer to make sure that the operation of your robots are technically legal, or to lobby for changing the current laws.

The Local Government

Collaborator

The local government owes you one favor. Use it well for the success of your robotic system.

Steve LaValle

Collaborator

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

I was never a big fan of patents, but now I have a couple.

The **Special resource cards** describe special robot abilities that are applicable to the design.

The **multiplier cards** can be applied on any resource card. They are associative: a $2\times$ and a $5\times$ cards that are applied together are equivalent to a $10\times$ card.

2× Multiplier

$\times 2$

Special

One resource can be multiplied in quantity by 2.

2× Multiplier

$\times 2$

Special

One resource can be multiplied in quantity by 2.

2× Multiplier

$\times 2$

Special

One resource can be multiplied in quantity by 2.

2× Multiplier

$\times 2$

Special

One resource can be multiplied in quantity by 2.

5× Multiplier

$\times 5$

Special

One resource can be multiplied in quantity by 5.

5× Multiplier

$\times 5$

Special

One resource can be multiplied in quantity by 5.

5× Multiplier

$\times 5$

Special

One resource can be multiplied in quantity by 5.

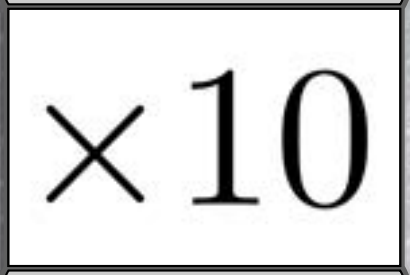
10× Multiplier

$\times 10$

Special

One resource can be multiplied in quantity by 10.

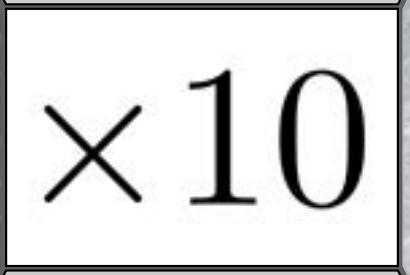
10× Multiplier



Special

One resource can be multiplied in quantity by 10.

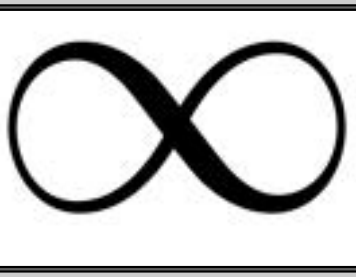
10× Multiplier



Special

One resource can be multiplied in quantity by 10.

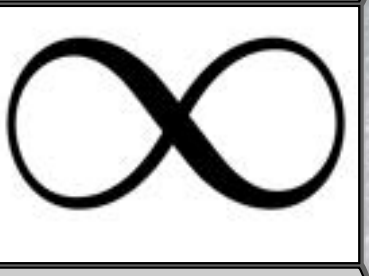
∞ Multiplier



Special

One resource can be multiplied in quantity by ∞.

∞ Multiplier



Special

One resource can be multiplied in quantity by ∞.

3D Printer

Special

You may print any object, as long as it fits in a 22 cm × 14 cm × 15 cm build volume.

Everything is now possible!

Consciousness Infusion

Special

Your robot is now conscious.
Does it make a difference?

AI Summer

Special

When this card is on the table, any paper whose description does not include the words “deep learning” is automatically rejected.

Ant-ifier

Special

You now have 1000 copies of your robot, but they are 1000 times smaller.

Would you be calm and placid
If you were full of formic acid?
– Ogden Nash

The **Platform cards** describe famous robots of the present and the past.

The platforms must be used as a whole, and they cannot be cannibalized for parts.

Note that not all robots have computation, not all have sensing capabilities, and so on.

Spot Mini

Platform

Spot Mini is an electrically powered quadruped that can handle objects and climb stairs. Its prensile "head-hand" combination places it squarely in the uncanny valley.

(Boston Dynamics)

Atlas

Platform

A relatively robust bipedal robot, battery powered, developed by Boston Dynamics.

If you saw Atlas, the giant who holds the world on his shoulders... what would you tell him?

PR2

Platform

The PR2 has two 7-DOF arms with a payload of 1.8 kg each, and an omnidirectional base.

(Willow Garage)

Shakey

Platform

Shakey was developed in 1966 at the Artificial Intelligence Center of Stanford Research Institute. It was equipped with an antenna for a radio link, sonar range finders, a television camera, on-board processors, and collision detection sensors.

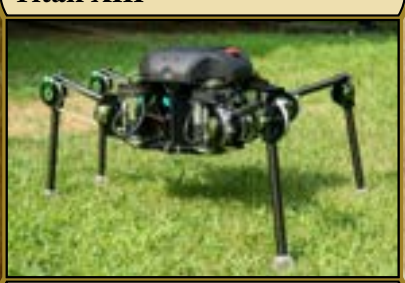
3D Hopper

Platform

The 3D Hopper was created in 1988 by Marc Raibert while at MIT, before he left to found Boston Dynamics. It can hop in place and follow simple paths.

Good wits jump; a word to the wise is enough.

Titan XIII



Platform

A sprawling-type quadruped robot that walks at 1.38 m/s, and is battery powered.

(Hirose/Fukushima laboratory, Tokyo Institute of Technology)

ACM-R5 Amphibious Snake

Platform

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

Now the serpent was more subtle than any beast of the field…

Gimball

Platform

A flying robot that can survive impacts with the environment due to the protective structure around it.

(Floreano group, EPFL)

Dragon Runner

Platform

A compact remote-controlled robot used by the British army, designed by CMU. It is lightweight, rugged, and equipped with a microphone, camera, and wireless modem.

RoboBee

Platform

The RoboBee is a miniature robotic insect, with a 3 cm wingspan and weighing 80 mg.

(Wood group, Harvard)

Duckiebot

Platform

The Duckiebot is an open source low-cost educational platform, designed as part of the Duckietown project. The Duckiebot's design is based on a Raspberry PI, and its only sensor is a fish-eye camera.

Octobot

Platform

The Octobot is an entirely soft robot. It is powered without electronics: microfluidic channels containing chemical reactions automate its movements.

(Lewis and Wood groups, Harvard)

ANYmal

Platform

ANYmal is a quadrupedal robot designed for operation in unstructured environments. Driven by special compliant and torque controllable actuators, it is capable of dynamic running and climbing.

(Hutter group, ETH Zürich)

Fish Robot

Platform

A fish robot made using soft robotics techniques. It is powered by gas canisters that inflate and deflate the internal hydraulics.

(Rus group, MIT)

Aibo

Platform

The Aibo robot has been the most sophisticated entertainment robot available to consumers. It was produced in the years 1999-2006.

(Sony)

Kiva Robot

Platform

Kiva created the first robotic warehouse, in which the robots moved the shelves to human workers, who were responsible for picking products and packing them. Kiva is now owned by Amazon.

(Kiva Systems/Amazon Robotics)

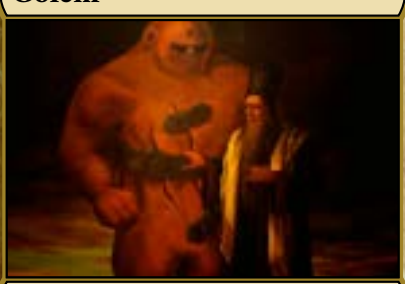
Roomba

Platform

The Roomba, first introduced in 2002, was one of the first consumer cleaning robots. The initial model relied on contact sensors and random turns to explore the environment.

(iRobot)

Golem



Platform

This 500 kg servant is made of clay.

Odd, however, your each byte is,
this fever of digitalitis!
Those beautiful computer chips
are nothing but ignited lips!
So let us pray that all is well
with Reb Judah Loew ben Bezalel!

R2 Astromech Droid

Platform

The popular series of astromech droids manufactured by Industrial Automaton.

"An extremely well put-together little droid."

AtlantikSolar

Platform

AtlantikSolar is the unmanned aerial vehicle (UAV) that has the record for the longest autonomous flight (81 hours) for any aircraft in the sub-50 kg category.

(Siegwart group, ETH Zürich)

Curiosity

Platform

The Curiosity rover, on Mars since 2012, has a mass of 899 kg. It can travel up to 90 m per hour on its six-wheeled rocker-bogie system, is powered by a RITEG.

(Caltech / Jet Propulsion Laboratory)

Sojourner

Platform

Sojourner landed on Mars on July 4, 1997 and explored the planet for around three months, before communication was lost. The rover was successfully reactivated in 2015 by Matt Damon.

(Caltech / Jet Propulsion Laboratory)

Spirit / Opportunity

Platform

Spirit and Opportunity have been exploring the planet Mars since 2003.

(Caltech / Jet Propulsion Laboratory)

Sky Crane

Platform

The most obvious solution to delivering a rover on Mars.

(Caltech / Jet Propulsion Laboratory)

The **Instant effects cards** describe special gameplay actions.

As a rule, the cards are discarded after use.

I Have an Idea!

Instant effect

If you receive this card, you can immediately take one of the empty cards included in the deck.
Think hard, and create a new card for the game. When done, put the new card in the deck and shuffle.
Discard this card after use.

I Have an Idea!

Instant effect

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Think hard, and create a new card for the game. When done, put the new card in the deck and shuffle.
Discard this card after use.

Fundamental Theorem

Instant effect

This card allows a reviewer to reject a paper by appealing to authority. The reviewer must reference a well-known specialist in the field.

The Fundamental Theorem of Robotics (Egerstedt, 2002) subsumes all subsequent results.

Theory of Everything

Instant effect

A reviewer can use this card to dismiss the paper as over-reaching. The reviewer must elaborate on this point. The card is discarded after it is used.

The results should be more concrete.

The Power of Friendship

Instant effect

During the paper submission phase, you can view and use one other player's cards, if they agree. If the paper is accepted, both players get a Name Recognition card.
The card is discarded after it is used.

Competitive Collaboration

Instant effect

During the paper submission phase, you can view and use one other player's cards. However, if the paper is accepted, only one of you, decided randomly, will get the *Name Recognition* reward.
Discard this card after use.

A Russian Did It in the 1960s

Instant effect

Unfortunately, it turns out that fifty years ago an unidentified Russian scientist had exactly the same idea as the paper under consideration. A reviewer can use this card to instantly reject the paper under review. Discard this card after use.

The Goal Posts Have Moved

Instant effect

You can change the current *Task* or *Environment* by picking a new random card. Discard after use.

"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."

Use the **Rewards cards** to keep track of the score.

Bitterness

Rewards

The first principle is that you must not fool yourself, and you are the easiest person to fool.
– Richard Feynman

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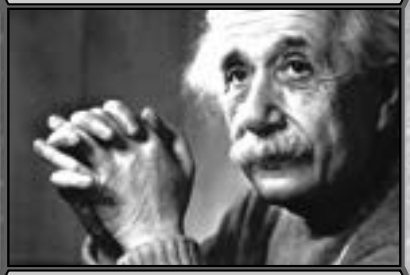
Name Recognition

Rewards

The problem in this business isn't to keep people from stealing your ideas; it's making them steal your ideas!
– Howard Aiken

In the picture, Marie Curie (1867–1934), French-Polish physicist.

Name Recognition



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In the picture, Rudolf Kálmán (1930–2016), faculty at ETH Zürich.

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In the picture, Claude Shannon, with a maze-navigating robot he built.

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In the picture, computer scientist Grace Hopper (1906-1992), US Navy.

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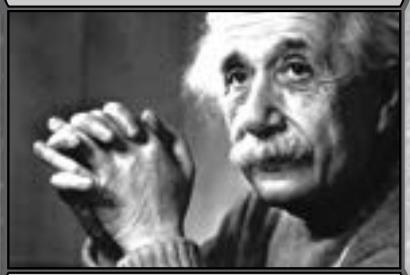

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Use the **Blank research cards** to create your own cards.

See the “I have an idea” card for details.

Blank actuator card

Actuation

Blank actuator card

Actuation

Blank sensing card

Sensing

Blank sensing card

Sensing

Blank energetics card

Energetics

Blank energetics card

Energetics

Blank computation card

Computation

Blank computation card

Computation

Blank communication card

Communication

Blank communication card

Communication

Blank form card

Form

Blank form card

Form

Blank data card

Data

Blank platform card

Platform

Blank special card

Special

Blank instant card

Instant effect

Blank collaborator card

Collaborator

Blank collaborator card

Collaborator

Blank task card

Task

Blank task card

Task

Blank environment card

Environment

Blank environment card

Environment