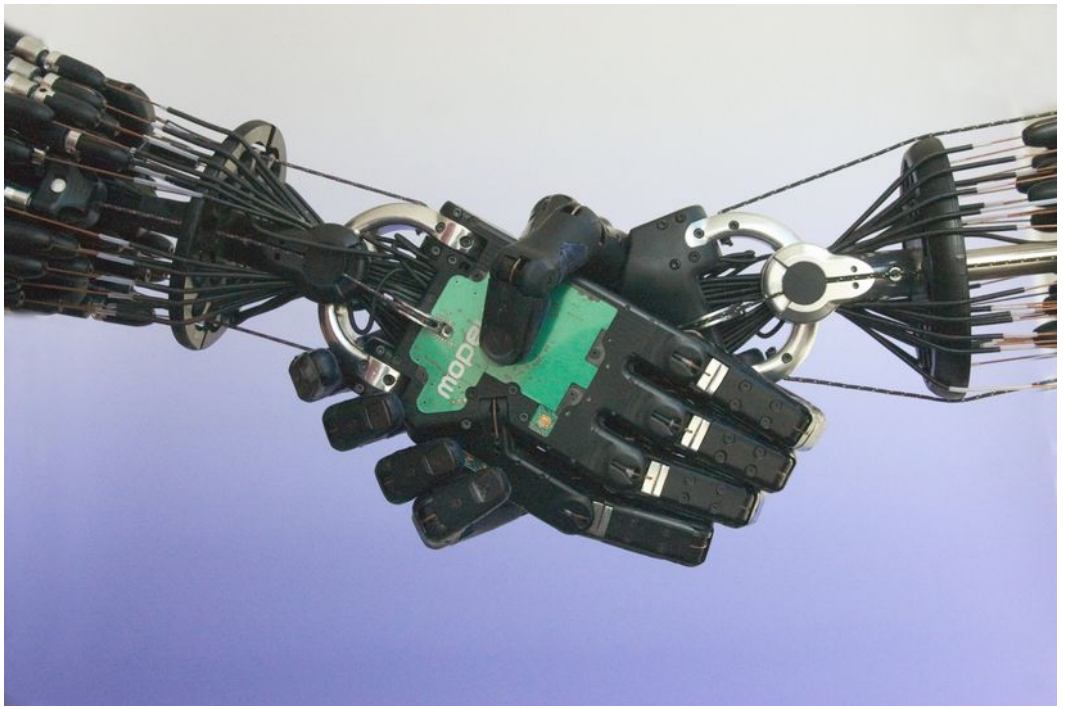
Shadow Robot Company



Rich Walker

Managing Director

rw@shadowrobot.com

Turning Ideas Into Profit

IagrE 2016

Corporate Summary

- Company established 1997 in London, UK
- Manufactures Hand product for R&D customers
- Significant internal and collaborative R&D
- Robotics technology development for clients
- Turnover ~£1.1M 2014, £1.3M 2015, might hit £2.5M 2016
- 24 staff covering all robotics hardware and software development
- Global distribution and sales in research
- Global network of collaborators and partners

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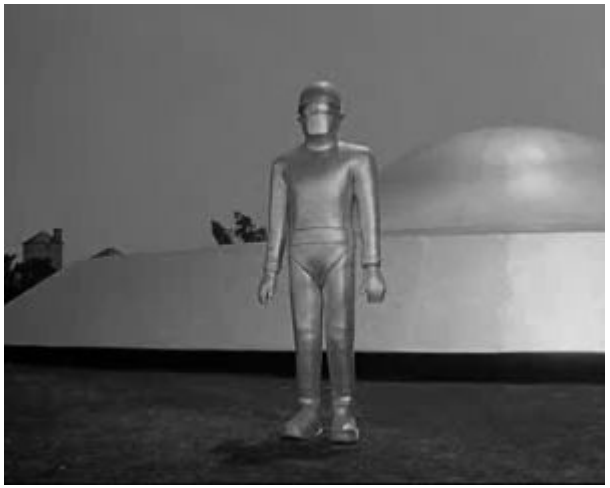
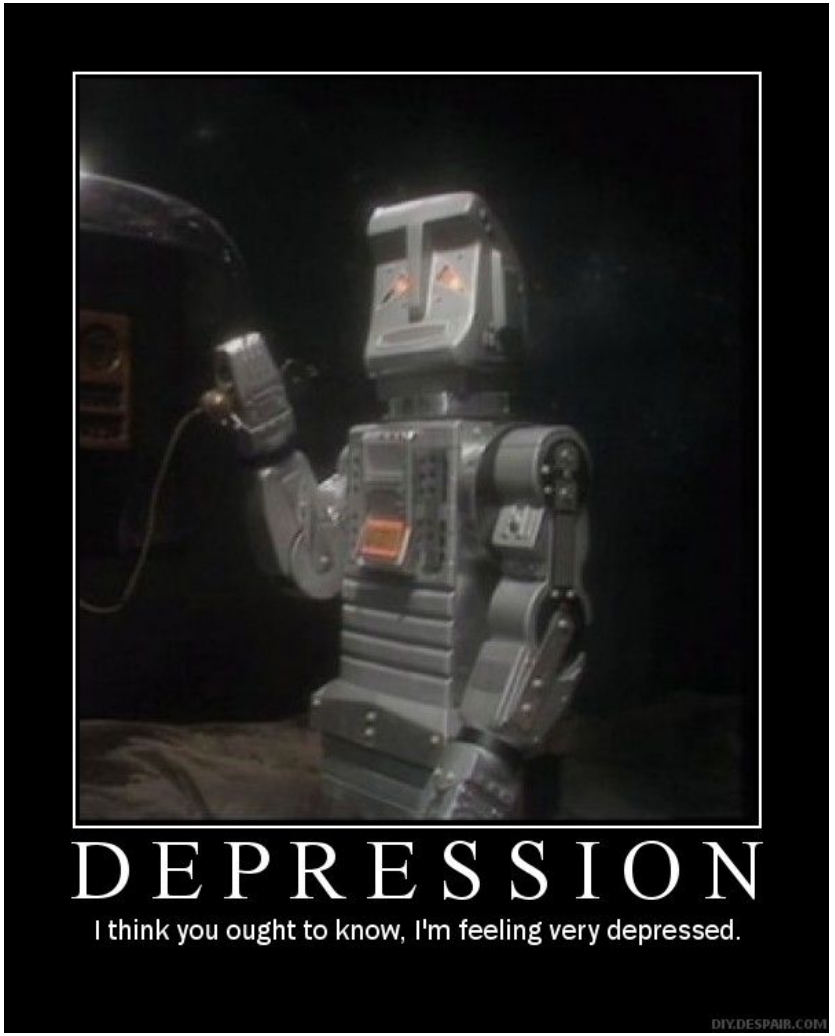
Influences...





Shadd
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Objective: Build useful robots

How does a robot get around the house?

1987-1995: The Shadow Biped
14 movements
Air Muscle actuation
Stood up using Fuzzy Logic, and the Alexander Technique

14 position sensors, 28 force sensors, 28 pressure sensors,
3 accelerometers, 10 load cells.

Then the first Honda bipeds appeared...

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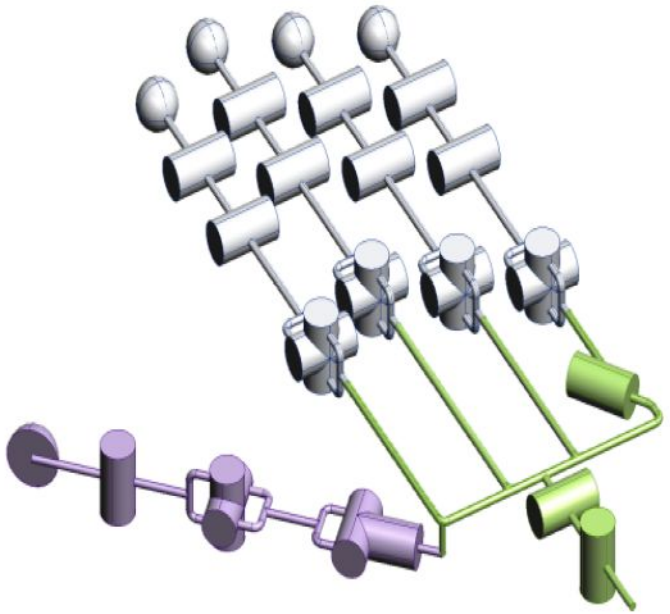
Dexterous Hand

If robots are going to be generally useful in the world, they will need hands like ours. This is the ultimate challenge in robotics.



20 brushless DC motors

40 strain gauges

40 tendons

24 joints

24 position sensors

25 temperature sensors

5 pressure sensors

26 microcontrollers

2 CANbus interfaces

1 EtherCAT interface

Built to order in London

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Not Just Hands

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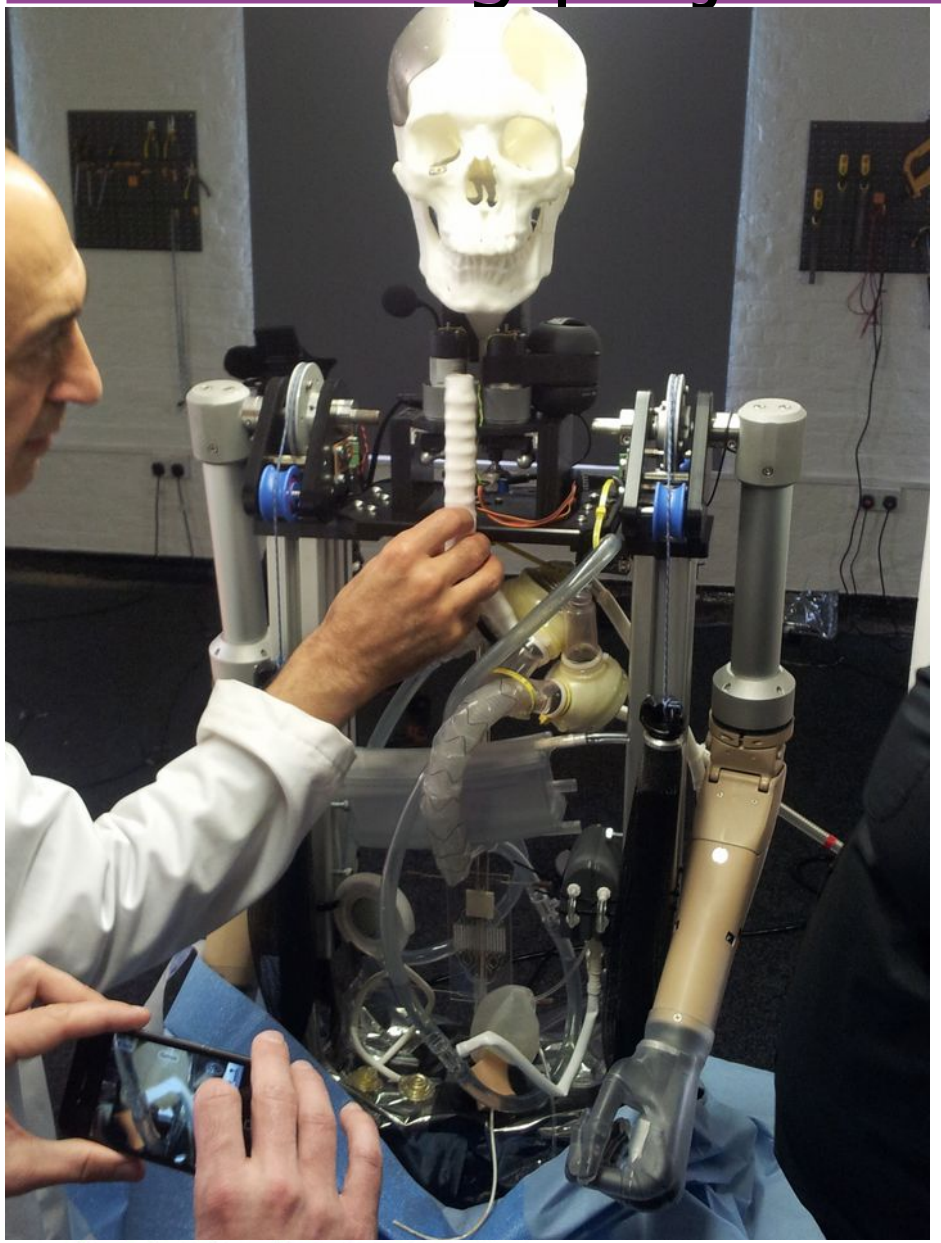
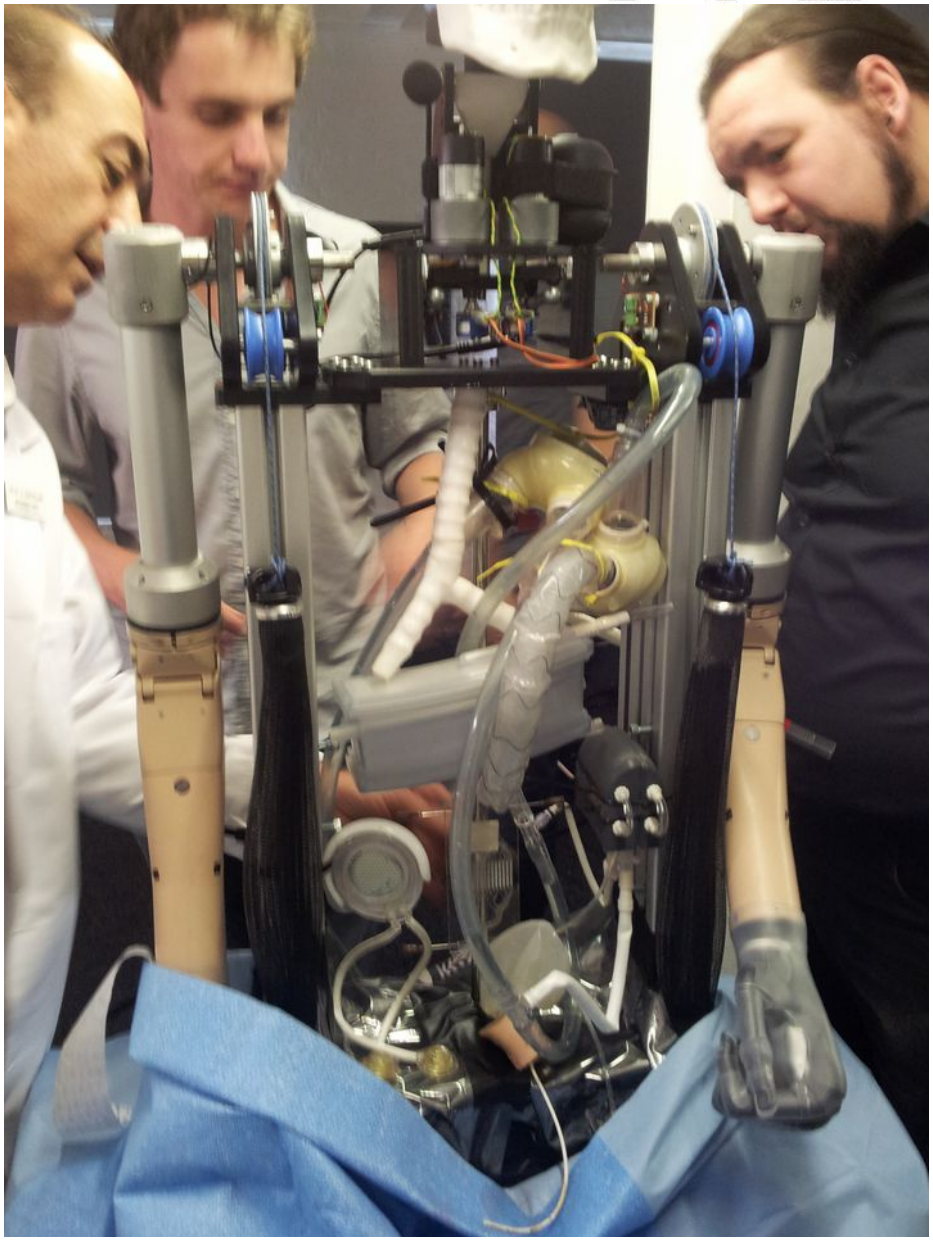
Interesting projects...





You Need A Market...

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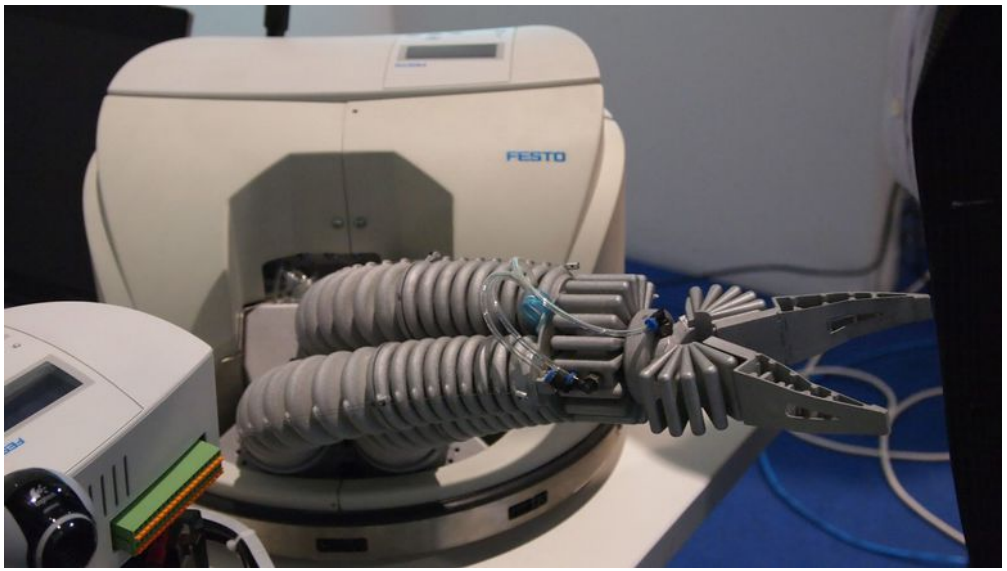
Robotics Segments

Figure 1: da Vinci surgical system



Robot Company

Finding/building a market...

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Hand as a product

- It sold by itself
- We had no idea why
- We optimised it for our early adopter
- We didn't understand what could be done with it.

A recipe for disaster!

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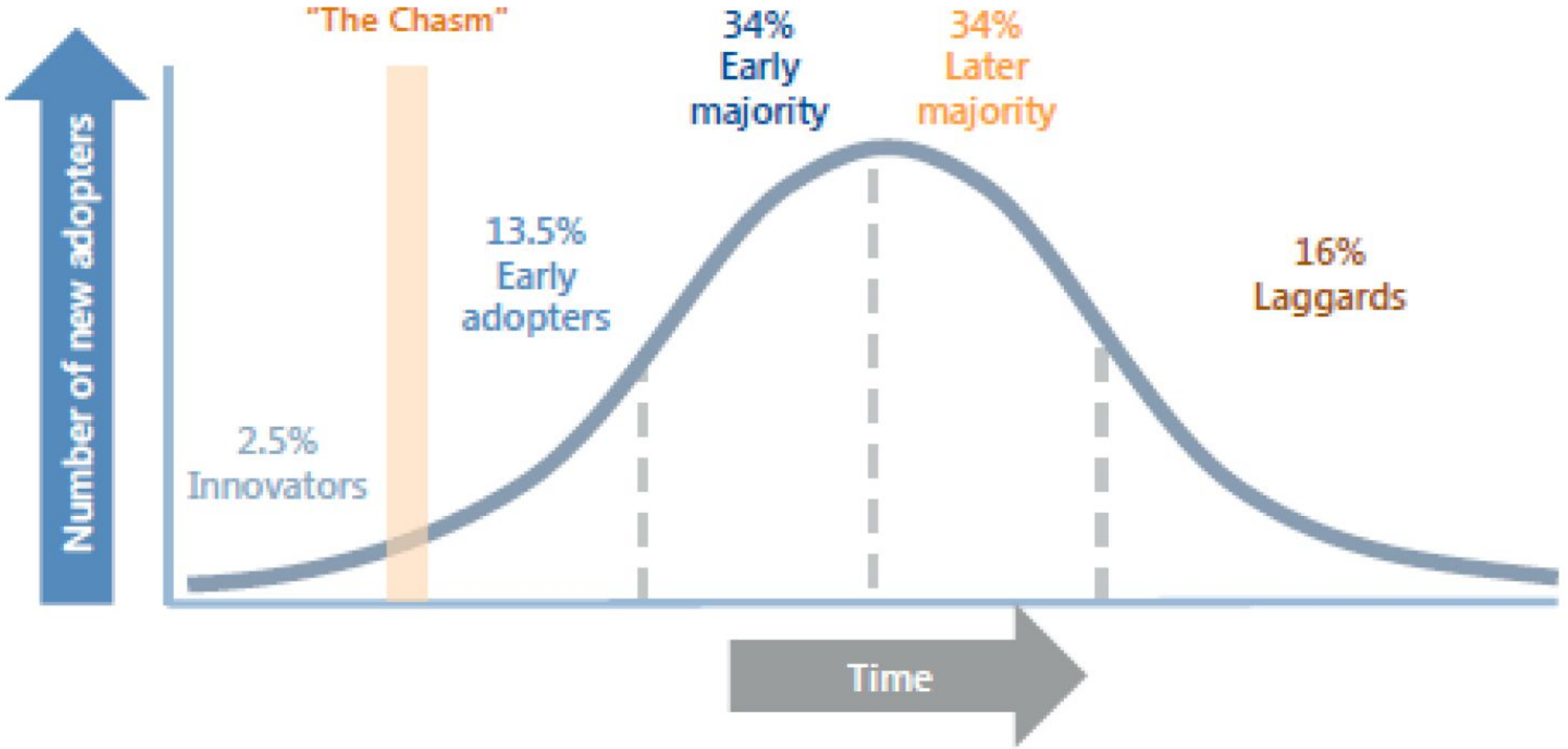
What didn't we know?

- Product lifecycles:



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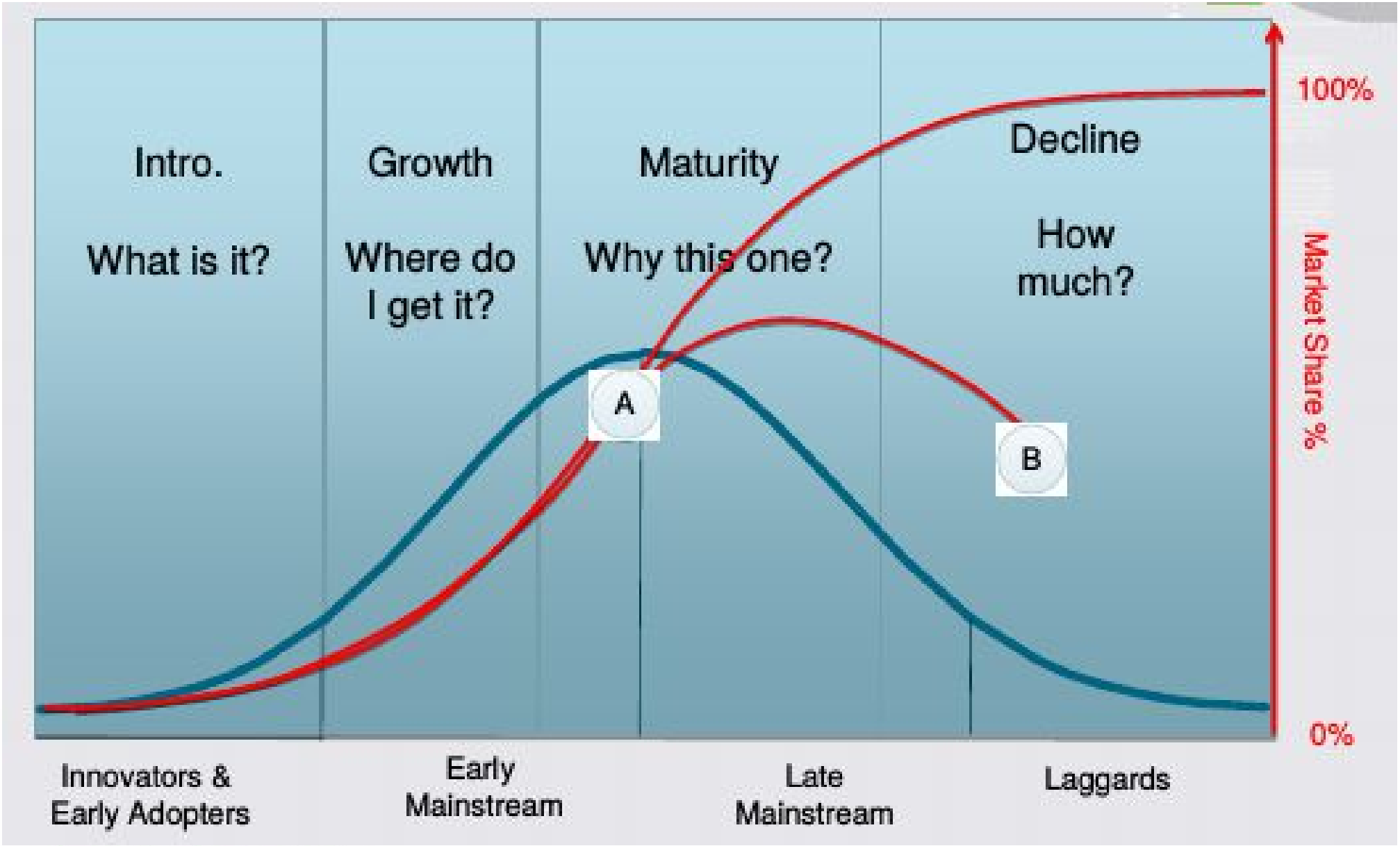
Geoffrey Moore, Crossing the Chasm

Why is that important?



Looking around - STEEPLED

- Societal
- Technological
- Economic
- Environmental
- Political
- Legislative
- Ethical
- Demographic

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Trends we consider

- Health and Safety – more stringent safety rules
- Nuclear renaissance (again) and decommissioning
- Global energy transition
- Aging society and demographic slump
- Increasing urbanisation and isolationism
- Bandwidth and computing is almost free
- Cameras/sensors are everywhere
- ROS!

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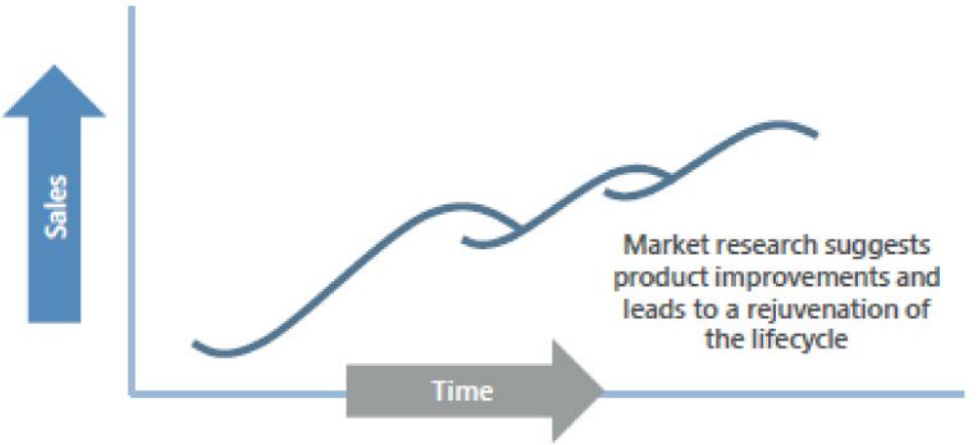
Suicide Leaps

	Old Market	New Market
Old Product	Existing product – Grow by sustaining innovation	Understand new customer needs and create new company profile. Adapt product.
New Product	Build on market position and customer understanding to create new revenue streams	Visionary leap.



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What else is a Hand good for?

- Research
- EOD
- Nuclear
- Biomedical
- Remote maintenance
- Remote presence
- Other people's robots
- Flexible automation

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What else is a Hand good for?

Research – existing market, “easy” sustaining innovation

- EOD – high barriers to entry
- Nuclear – high barriers to entry
- Biomedical – research focussed customers
- Remote maintenance – credibility and systems gaps
- Remote presence – cost gap
- Other people's robots – evolve product into component
- Flexible automation – real market, real challenges

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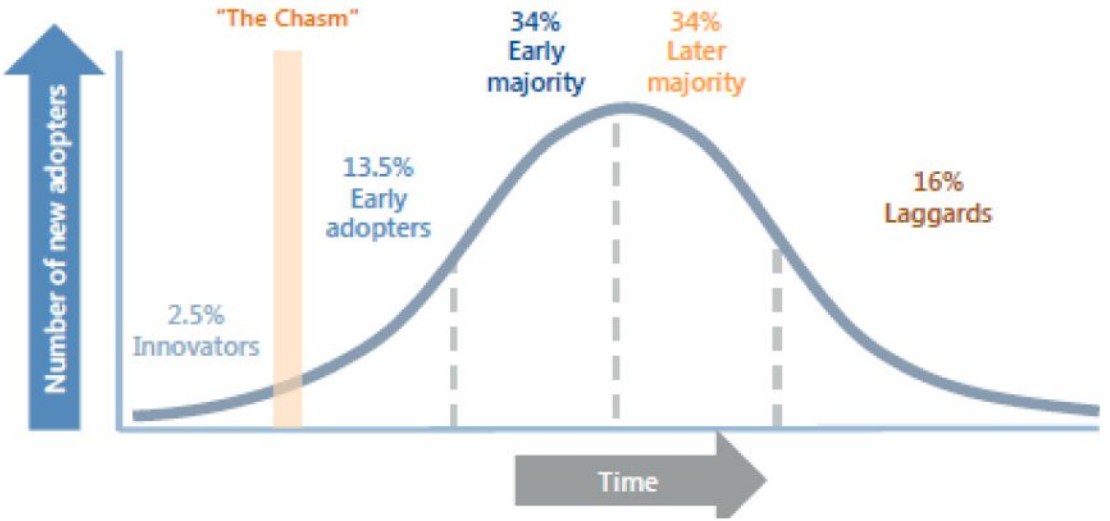
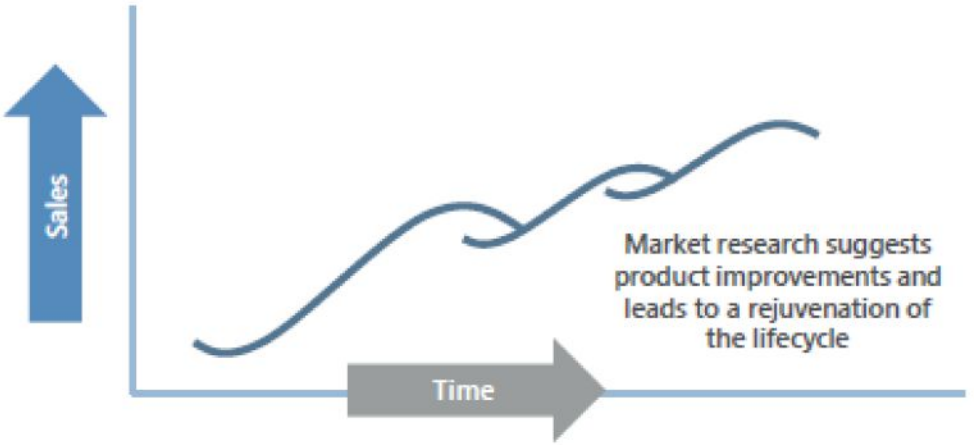
Markets for Hands

- Robotics Research
- EOD
- Nuclear
- Biomedical
- Remote
  - Maintenance
  - Presence
- Other people's robots
- Flexible automation





The "Hand Product" has a curious market lifecycle, due to the need for supporting technologies which Shadow has worked to develop.

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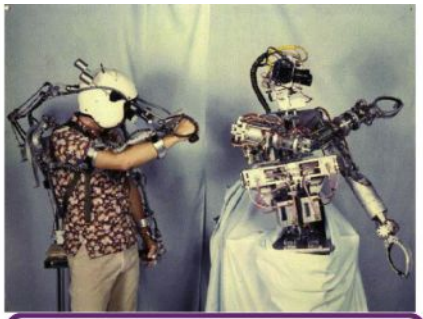
Manipulation Lattice



Greenman Teleoperator

Dexterous Hand

Teleoperation

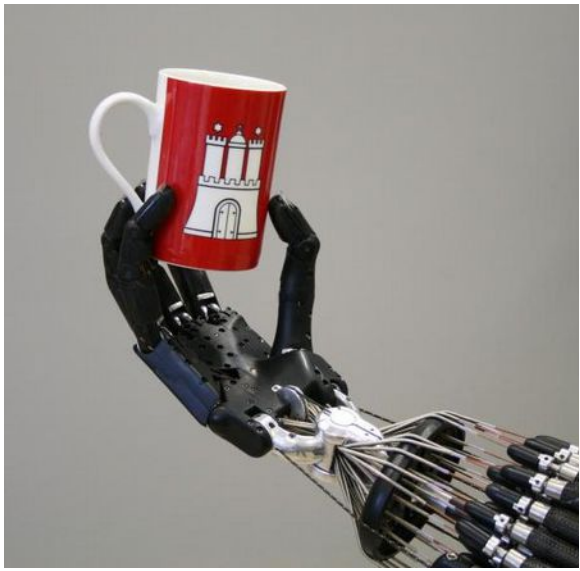
Autonomous manipulation

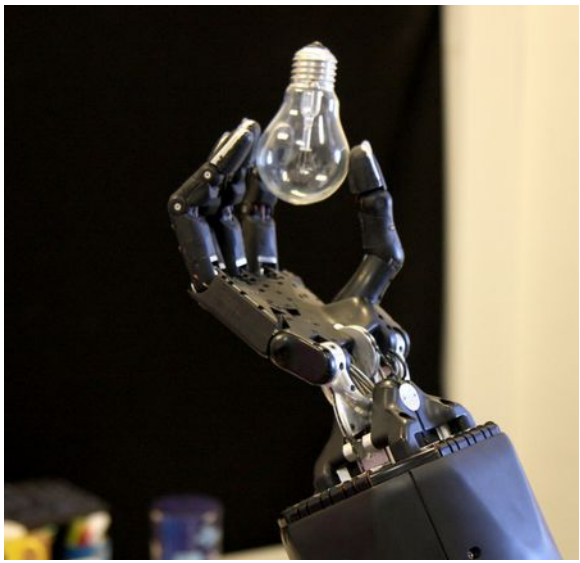
Intelligent, personalized, bimanual telemanipulation

This region is interesting for robot deployment

Current Capabilities

- Core Dexterous Hand
- Stable grasps of known objects
  - By demonstration
  - Generalisation
- Motion planning with objects
- Task oriented grasping
  - Hold for use
  - Regrasp in limited cases





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Where do we see opportunities?

- Focus areas:
  - Manipulation and Grasping
  - Making “new” robots
- Strategy:
  - Develop core technology
  - Domain-specific development projects
  - License core tech into domains
  - Sell product/services in domains

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Dexterity

- Building the dexterous manipulation “pipeline”:
  - See - static model - localise - reach - grasp - hold stably - dynamic model - move - orient - interact - place - release
- Developing sensing modalities
  - exploiting existing and new sensor data, sensor fusion, modelling and characterisation.
- Developing more deployable dexterous hands
- Developing sensing and control
  - improve performance and reliability of the hand and of the grasping/interaction
- Modelling and prediction of grasping and interaction

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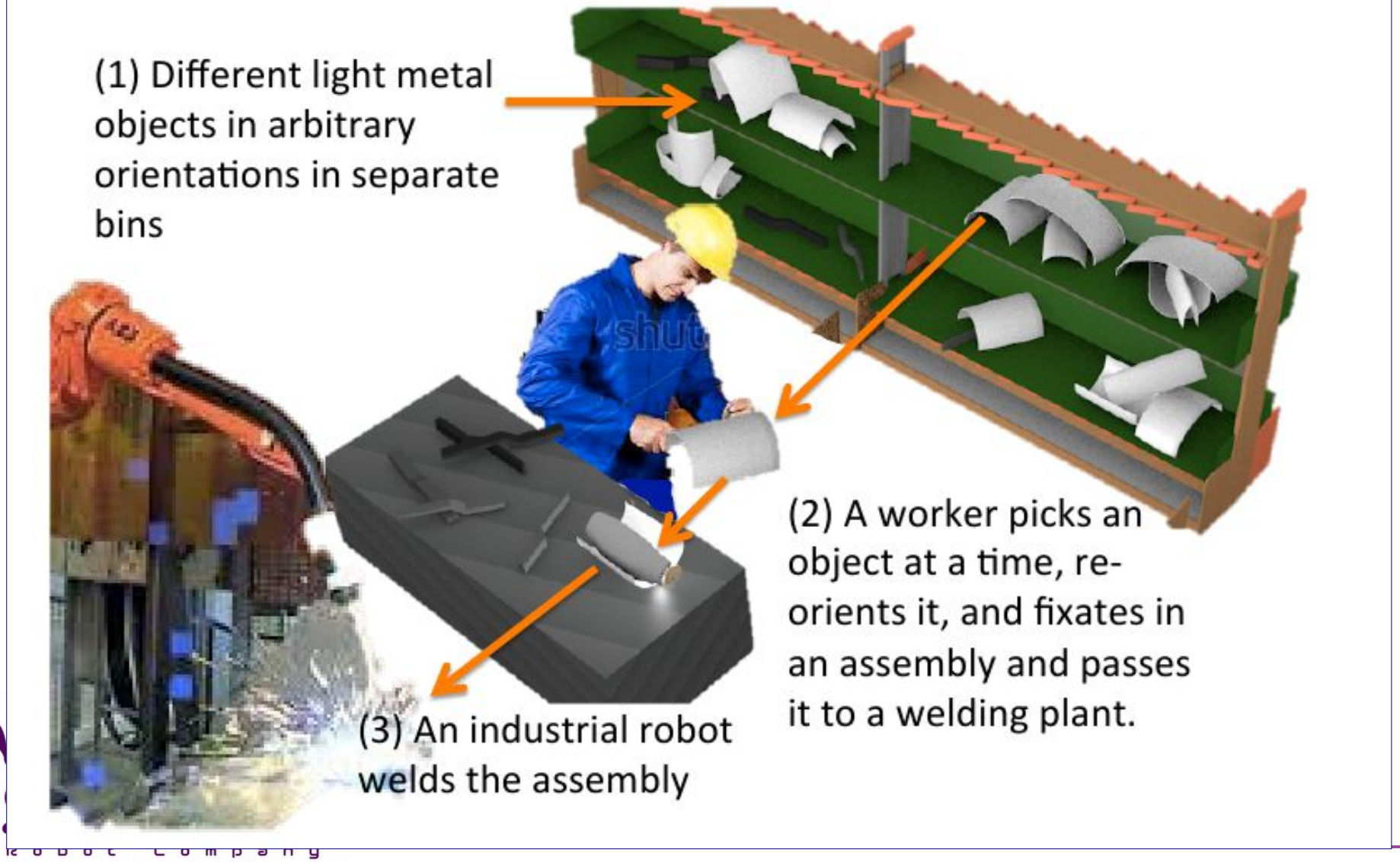
In-factory logistics



Flexible Manufacturing in Food

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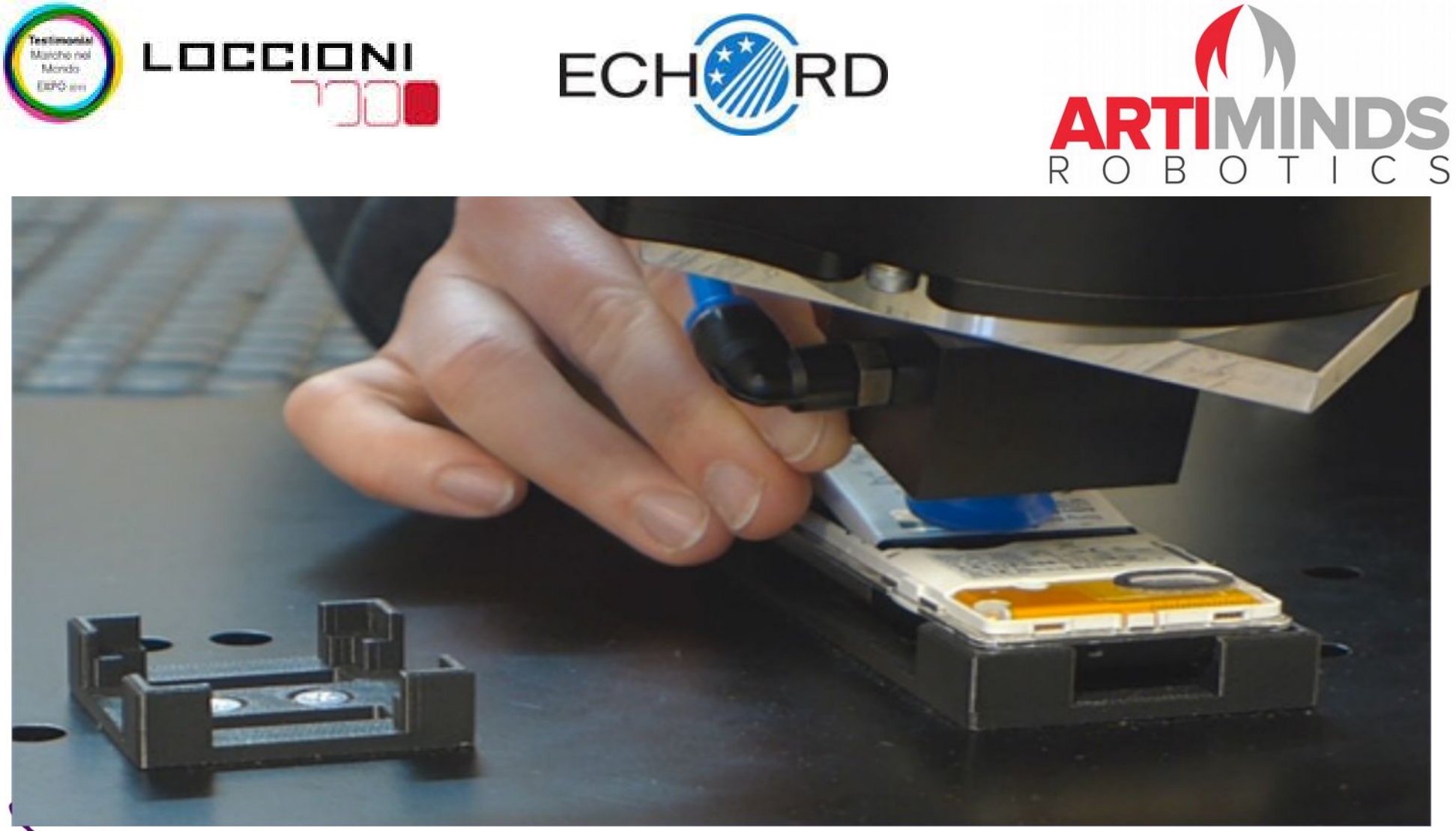
Packaging fruit requires manual intervention at present

DexBuddy – PbD for assembly



AUTOPIC – Strawberry Harvesting

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BerryWorld

NPL National Physical Laboratory

Harper Adams University

Telemetry Associates Ltd
Consultants in Telemetry Applications

AUTOPIC

the AUTOPIC project (ref: 101814) is part funded by Innovate UK Technology Strategy Board and BBSRC 20 Years of Pioneering Great British Bioscience

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AUTOPIC HaaS Lean Canvas - 20160828

<table>
<tr>
<td rowspan="2">Problem

Lack of humans to harvest strawberries

High cost of humans to harvest (£0.25/punnet)

Price pressure on growers</td>
<td>Solution

Subcontract harvesting

Using robot “pickers” that harvest cheaply

So cost base is fixed

With ripeness analysis</td>
<td rowspan="2">Unique Value Proposition

AUTOPIC – automated strawberry harvesting. Reliable, cheap, safe precision harvesting..</td>
<td>Unfair Advantage

2 year funded development project leading to prototype

IP lock around project

Direct link to growers</td>
<td rowspan="2">Customer Segments

Strawberry growers in UK and globally – e.g. BerryWorld.

Early Adopter:
Neill@Berryworld</td>
</tr>
<tr>
<td>Key Activity/Metric

Manufacturing cost/picker

Operating cost/punnet

Number of growers using

Pick quality metric</td>
<td>Channels

Start with growing companies we know (BerryWorld) and then sell service elsewhere.</td>
</tr>
<tr>
<td colspan="2">Cost Structure

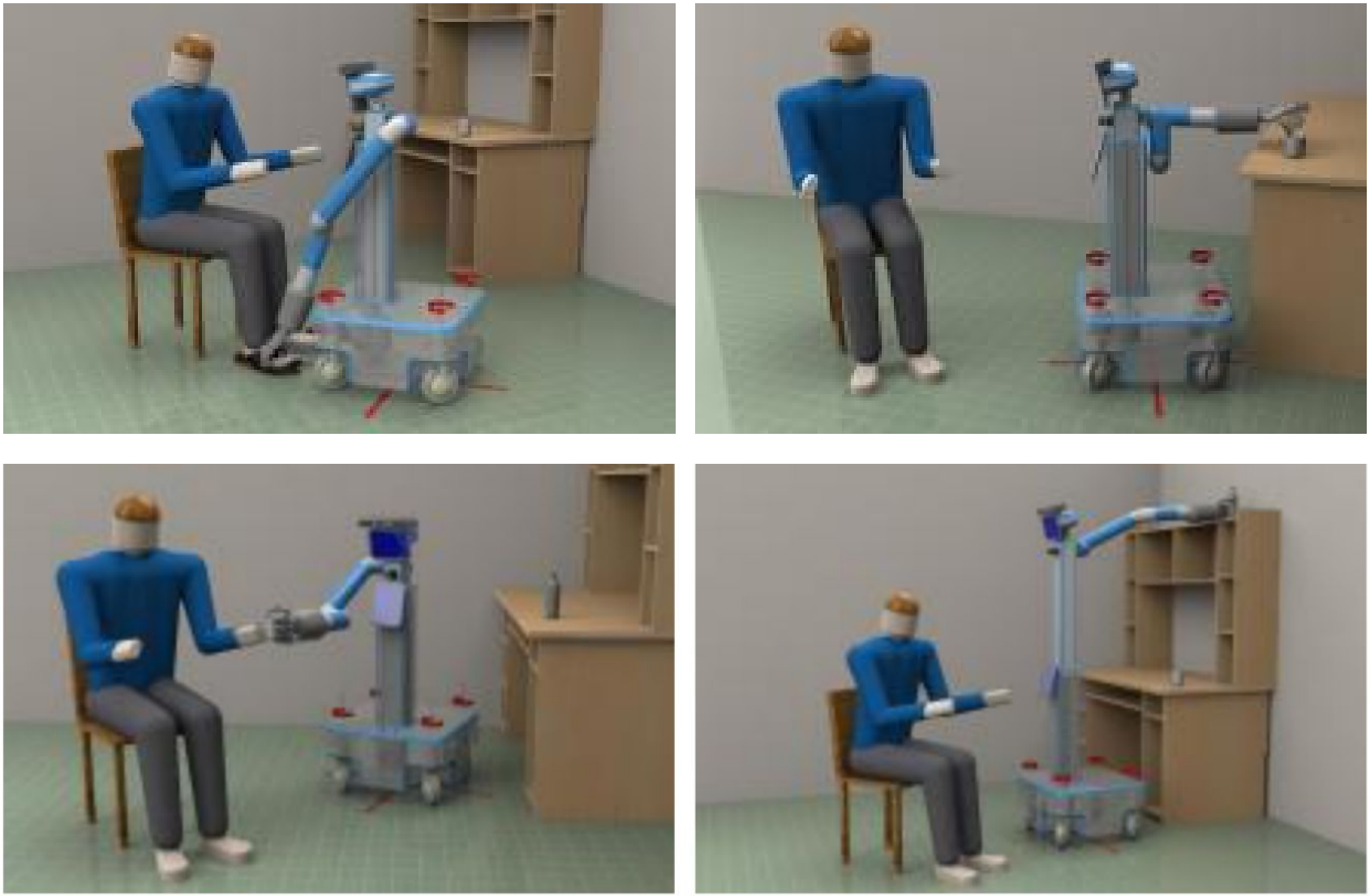
Production team - £17k/mo
Development team - £30k/mo
Deployment team - £8k/mo/team

Mfr materials - £10k/robot</td>
<td colspan="3">Revenue Stream

£0.25/punnet harvested
1 punnet every minute

£120/day/picker
£21k/picker in 6 months</td>
</tr>
</table>

RAMCIP – Assistant for MCI



RAMCIP is developing a new type of assistive robot

CHIRON

Care at Home using Intelligent Robotic Omni-functional Nodes

User Experience Design & Enabling Technologies
Designability

Assistive Robotics and Intelligent Sensors
Bristol Robotics Lab

Robotic Manipulators and Controllers
Shadow Robot Company

Older people and Carers
Three Sisters Care

Project Management
Telemetry Associates

Feasibility
Smart Homes & Buildings

The Team

designability
Bath Institute of Medical Engineering

Three Sisters Care
Dedicated assistance in your own home

brl
Bristol Robotics Laboratory

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SH&BA
Smart Homes and Buildings Association

TA
Telemetry Associates Limited
Consultants in Telemetry Applications

- Modular and Extensible
- Adaptable to Changing Needs
- Updatable via Cloud-Based Services
- Stylised to fit with decor
- Customisable to personal preferences

Moley Robotics

- Entrepreneur with vision and finance
- Prototype from COTS hardware
  - Hand, UR-10, PhaseSpace, CyberGlove
- Bringing in supporting team
  - chef, designer, manufacturer, PR, I-UK
- Rapid iteration and demo delivery
  - 5 months to first internal demo, 8 months to first public demo
- Technical roadmap for whole system delivery
  - manufacturing partners and developers identified
- Generation of new IP for client
  - 3 initial filings
- License of technology for client's specific domain

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Robotics Development

- Developing robots in new areas based on Shadow skills:
  - Harvesting (AUTOPIC, AUTOMATO)
  - Food processing (Moley)
  - Manufacturing (Pharma, White Goods)
  - Assistive technology (RAMCIP)
  - Care (LTCR-CHIRON)
  - Factory Manual Processes (COROMA)

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Teleoperation

- Applying dexterity to teleoperation
  - Marine
  - Aerial
  - Distant
  - Nuclear
  - Sterile
    - Pharma
    - Semiconductor
- Building the teleoperation "system":
  - immersive (or not) user interfaces - haptic or not
  - developing system for application domains
  - mapping between process plans and human motions to drive robots ("abstract teleoperation", "conducting the robot")

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ROS Ecosystem

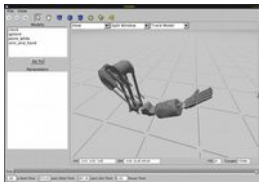
Developers

SWRI

Fraunhofer

Shadow

Any Robot Designer!



Distribution

Topic

Simulator

Cluster

Package

ROS

Model

Service

Parameters

Node

Robots

Components

Integration

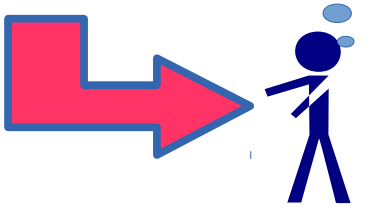
SLAM

MoveIt

Navigation

Kinematics

Robot Idea



Electric → Fuerte → Groovy → Hydro → Indigo

Roadmap

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How to look for markets?

Innovate → Develop → Market → Sell

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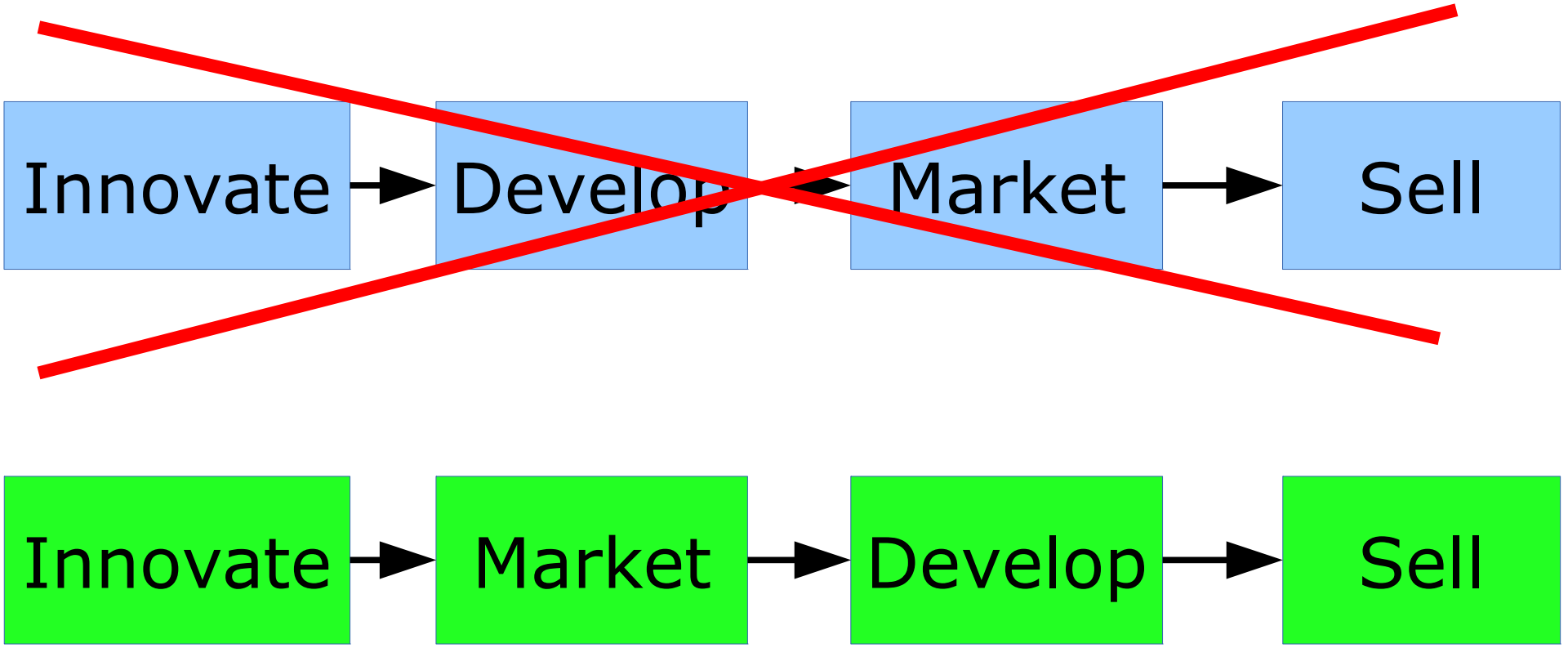
How to look for markets?



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The Business Model Canvas

Designed for:

Designed by:

On:

Iteration:

Key Partners

Who are our Key Partners?
Who are our key suppliers?
Which Key Resources are we acquiring from partners?
Which Key Activities do partners perform?

Key Activities

What Key Activities do our Value Propositions require?
Our Distribution Channels?
Customer Relationships?
Revenue streams?

Key Resources

What Key Resources do our Value Propositions require?
Our Distribution Channels? Customer Relationships?
Revenue Streams?

Value Propositions

What value do we deliver to the customer?
Which one of our customer's problems are we helping to solve?
What bundles of products and services are we offering to each Customer Segment?
Which customer needs are we satisfying?

Customer Relationships

What type of relationship does each of our Customer Segments expect us to establish and maintain with them?
Which ones have we established?
How are they integrated with the rest of our business model?
How costly are they?

Channels

Through which Channels do our Customer Segments want to be reached?
How are we reaching them now?
How are our Channels integrated?
Which ones work best?
Which ones are most cost-efficient?
How are we integrating them with customer routines?

Customer Segments

For whom are we creating value?
Who are our most important customers?

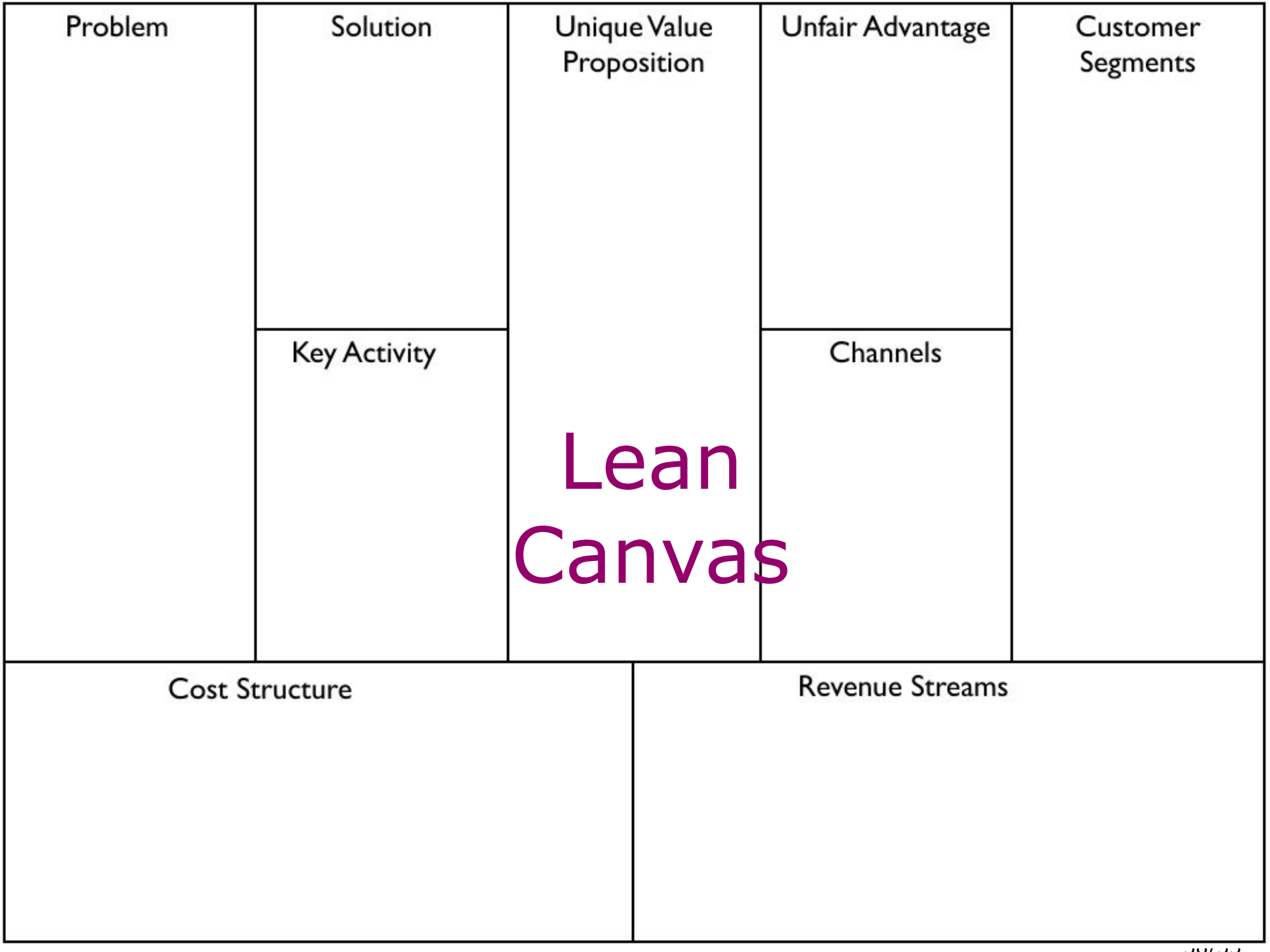
Cost Structure

What are the most important costs inherent in our business model?
Which Key Resources are most expensive?
Which Key Activities are most expensive?

Revenue Streams

For what value are our customers really willing to pay?
For what do they currently pay?
How are they currently paying?
How would they prefer to pay?
How much does each Revenue Stream contribute to overall revenues?

www.businessmodelgeneration.com


Problem
Solution
Unique Value Proposition
Unfair Advantage
Customer Segments
Key Activity
Channels
Lean Canvas
Cost Structure
Revenue Streams

Next Generation

Grasping & Manipulation

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Deployment Gap

Capability

Capability Gap

Time

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Comparison

	Schunk 3F	Barrett Hand	Adroit MK2	Robotiq	Allegro	Schunk 5F	Prensilia	Active AR10	Shadow Hand E
Weight (kg)	1.95	0.98	1.6	2.3	1.09	1.3	0.64	0.475	4.2
No. of Fingers	3	3	3	3	4	5	5	5	5
DoF	7	4	4	9	16	9	5	10	20
DoM	7	8	-	-	-	20	11	-	24
Payload (kg)	-	6	23	10	5	-	5	-	5









~~Dexterity~~ Grasping

- Building the dexterous ~~manipulation~~ grasping "pipeline":
  - See - static model - localise - reach - grasp - hold stably - dynamic model - move - orient - interact - place - release
  - Developing sensing modalities - exploiting existing and new sensor data, sensor fusion, modelling and characterisation.
  - Developing more deployable dexterous ~~hands~~ grippers
  - Developing sensing and control to improve performance and reliability of the hand and of the grasping/interaction
  - Modelling and prediction of grasping and interaction

Commercial Need is Grasping!

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Grasping Hand

Goals – based on both needs of RAMCIP project and commercial requirements

- Lightweight Hand that will fit onto "all" mobile robotic arms – Baxter, Fetch, TIAGo…
- Handle complete YCB (Yale-Carnegie-Berkeley) Object Set
  - 77 objects across daily life
- Also handle "customer use case" objects
  - outside EU project scope
- Robust and compliant - safe Human Robot Interaction
  - RAMCIP requires safe interaction with an elderly person suffering from MCI/ early stages of Alzheimer's
- Non-anthropomorphic
  - Doing away with 'Hand and Forearm'
  - Focus more on an end-effector
- Intuitive UI for non-programmers: easy to setup/use a new grasping strategy.

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This work is part funded by the European Commission in the RAMCIP project under contract number 643433

Grasping Hand

Differences

- Focussing on dextrous gripping and grasping, not manipulation
  - Not just grasping many objects, but grasping them well
  - Knowing whether or not grasping succeeds
- In-hand vision for grasp selection and maintaining grip
- Ambidextrous, can be fitted as both a left or right Hand
- Modular architecture from the ground up
  - Permits later versions to have additional features (or more fingers!)

Shadow Robot Company

This work is part funded by the European Commission
in the RAMCIP project under contract number 643433

Grasping Hand?

Numbers

- 3x 3-DoF Finger
- 2-DoF wrist module
- ≥1.5kg payload
- Weight <2kg
- Competitive in market
- 10 kHz torque control loop / 1kHz position control loop
- Scalable to stronger/larger for customer designs

Shadow Robot Company

This work is part funded by the European Commission
in the RAMCIP project under contract number 643433

Feed-in, linkages, gearing

- CERN – Radiation testing
- RAMCIP – core development funding
- Moley – funded core teleop demonstrator
- HANDLE, GSC – collaborations that developed core technologies
- COROMA – mobile integration
- CLOPEMA – 3d vision technology
- Offshore – validation and deployment in shallows
- Pharma – development projects leading to deployment, license
- Flexible manufacture – on-ramp to production
- Aerospace engineering – future development project

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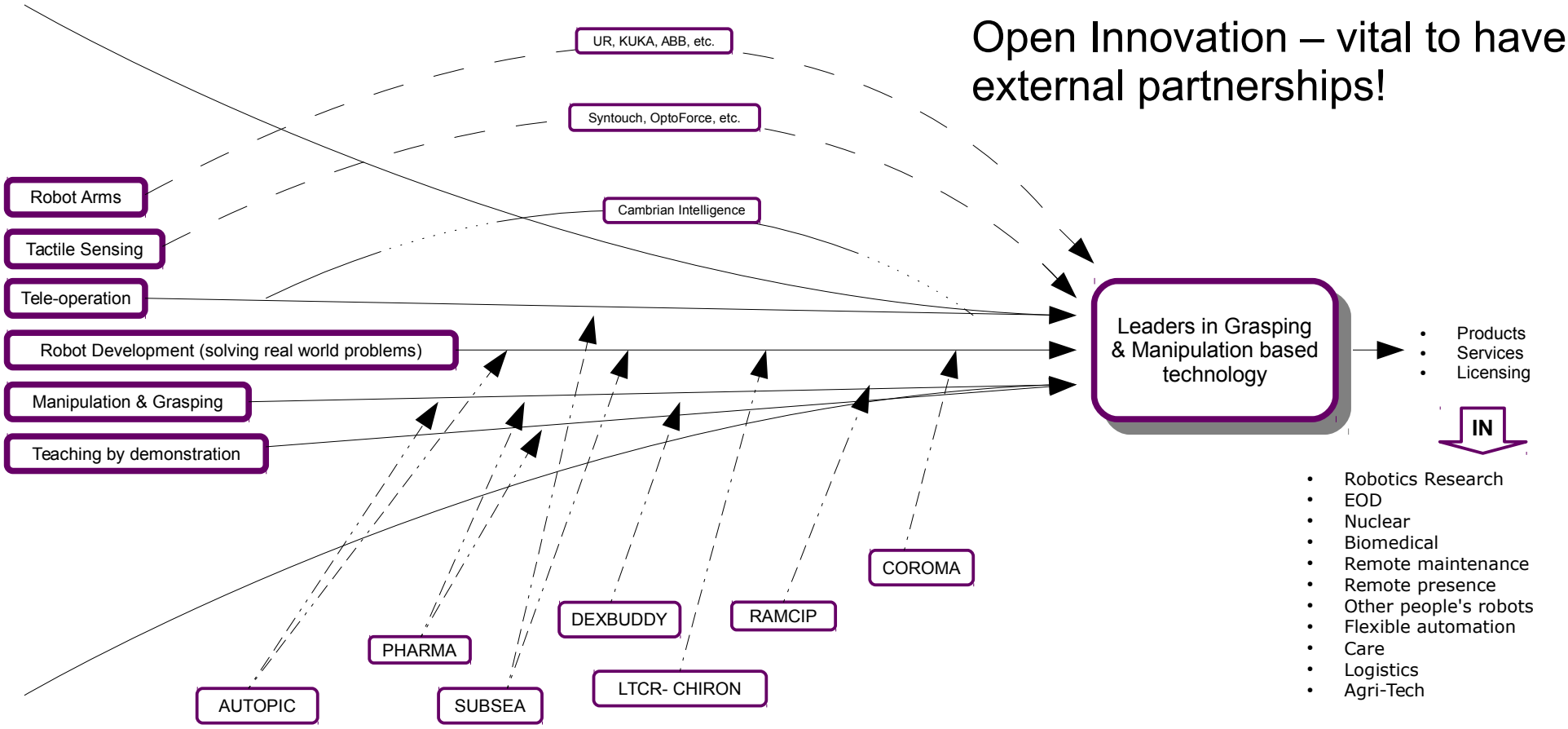
Roadmap


Open Innovation – vital to have external partnerships!
UR, KUKA, ABB, etc.
Syntouch, OptoForce, etc.
Cambrian Intelligence
Robot Arms
Tactile Sensing
Tele-operation
Robot Development (solving real world problems)
Manipulation & Grasping
Teaching by demonstration
Leaders in Grasping & Manipulation based technology
Products
Services
Licensing
IN
Robotics Research
EOD
Nuclear
Biomedical
Remote maintenance
Remote presence
Other people's robots
Flexible automation
Care
Logistics
Agri-Tech
COROMA
DEXBUDDY
RAMCIP
PHARMA
LTCR- CHIRON
AUTOPIC
SUBSEA
2016
Collaborations and development projects
2020

Where do the resources come from to keep innovating?

(three more Geoffrey Moore slides,
This time from “Dealing with Darwin”)

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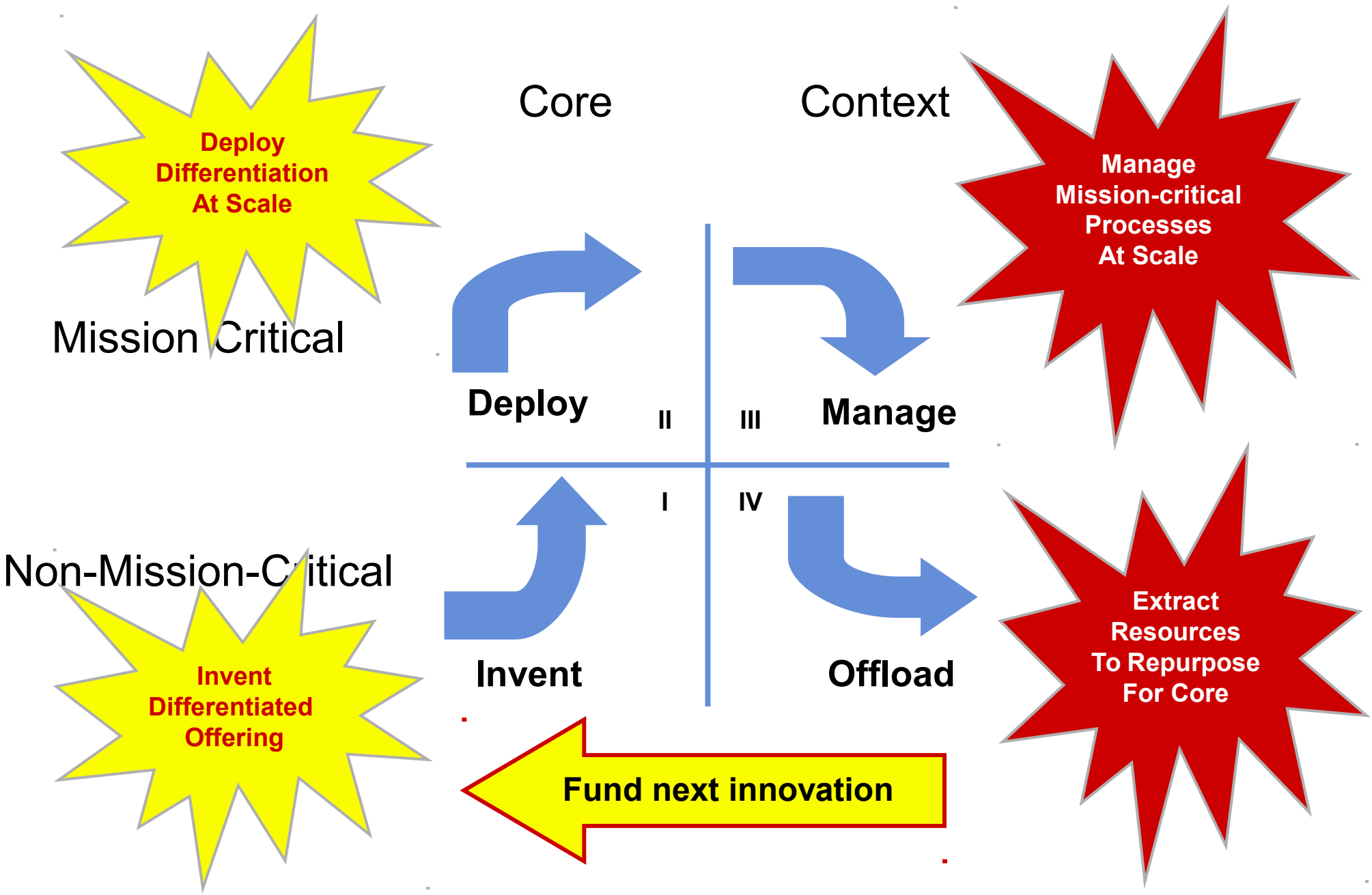
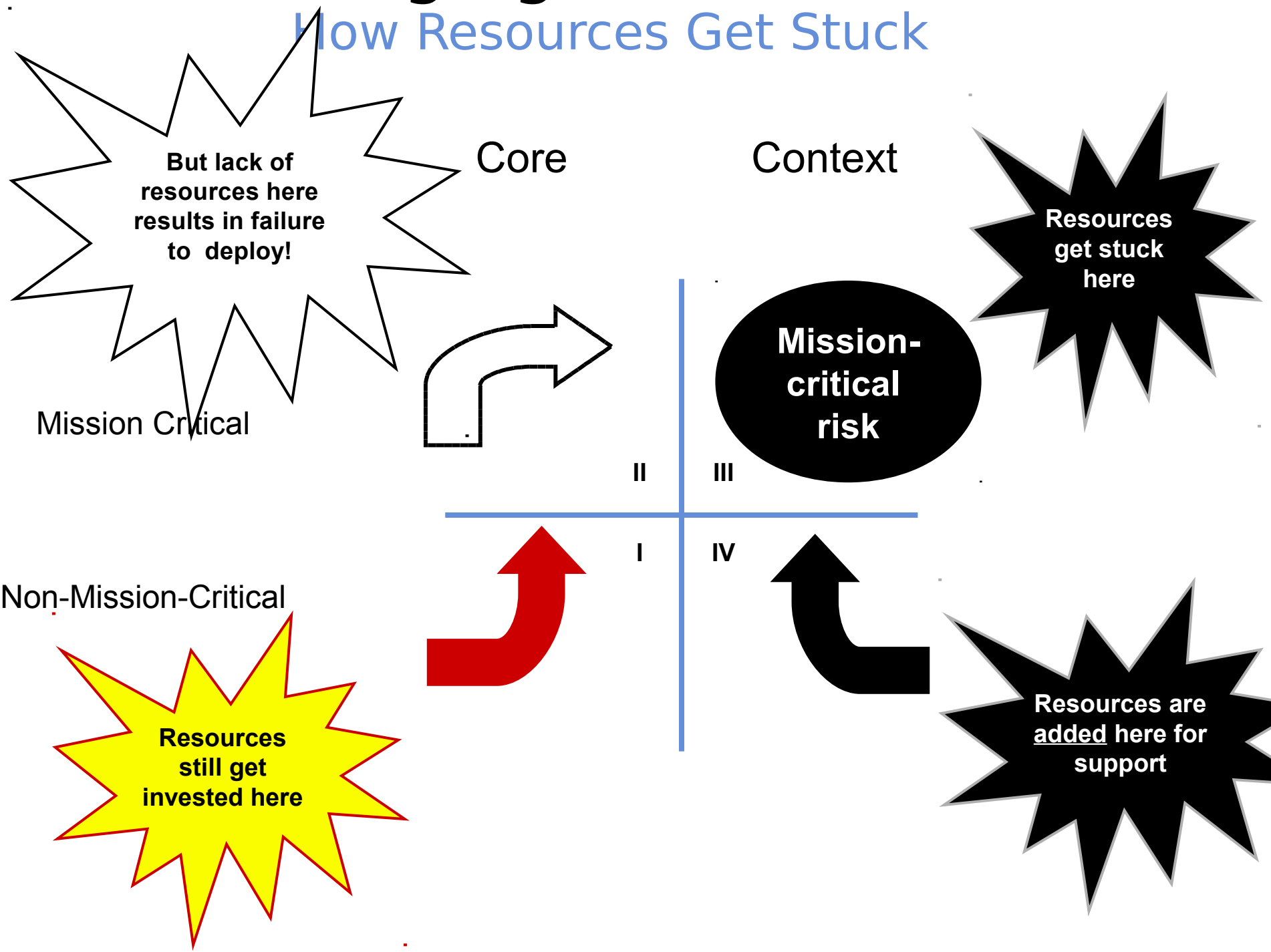
The Cycle of Innovation

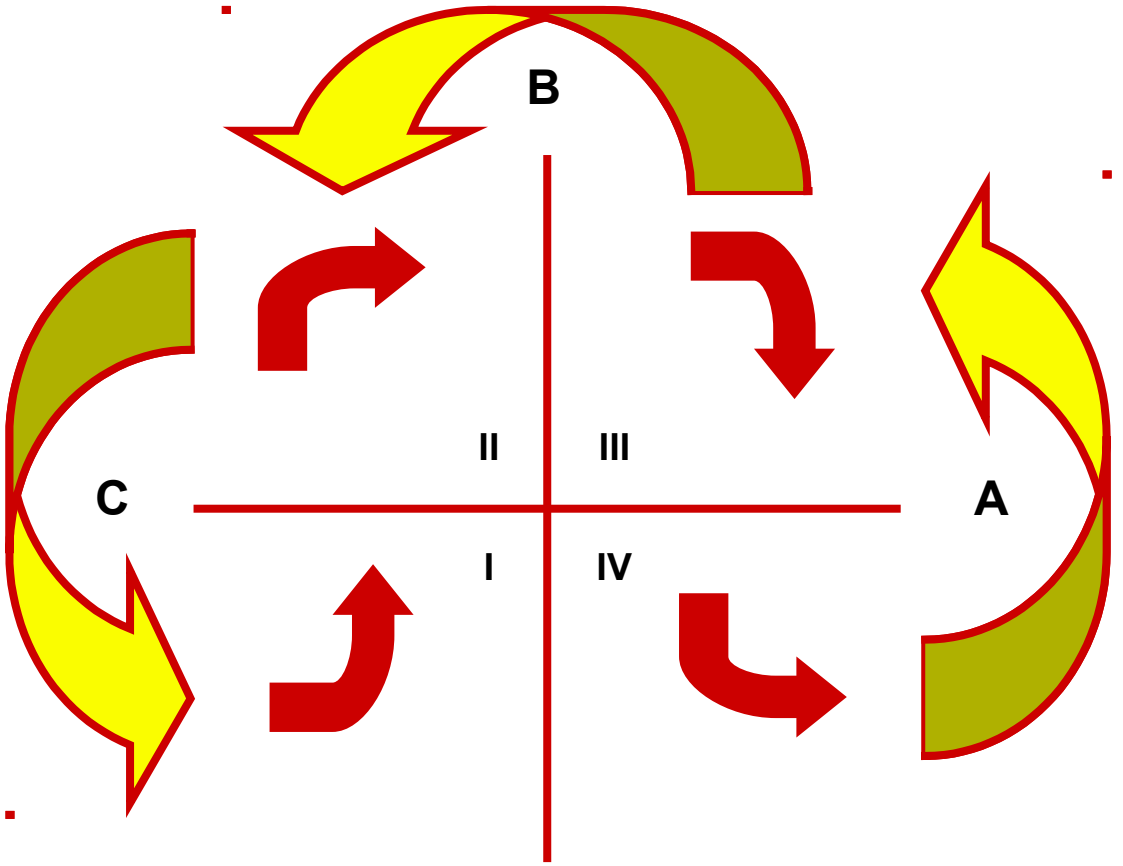


Clinging to Context

How Resources Get Stuck



Resource Recycling



Work circulates clockwise

People recycle counter-clockwise

Reading List

- Crossing the Chasm – Geoffrey Moore
- Innovators Dilemma – Clayton Christiansen
- Lean Startup – Eric Ries
- Business Model Generation - Alexander Osterwalder and Yves Pigneur
- The Startup Owners Manual – Steve Blank
- Good to Great – Jim Collins

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In Summary

- Find a real problem
- Test your understanding of the problem on the market
- Then develop prototypes!
- Find support
- Find more support!!
- Persist. (Longevity is it's own reference!)

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