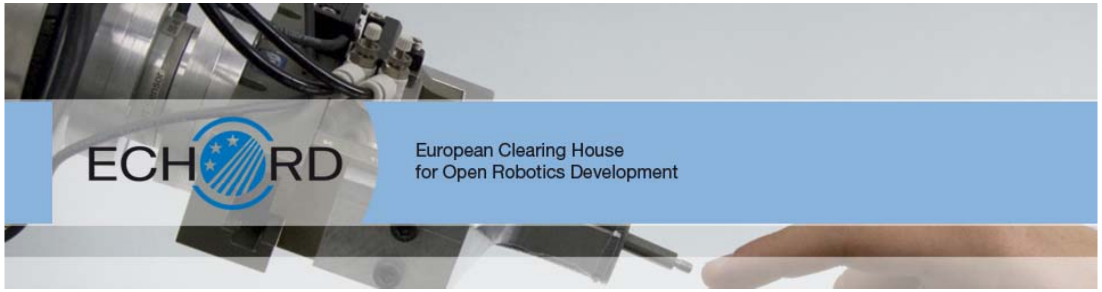


ECHORD Opening Event

Deutsches Museum, Munich, Germany
September 4, 2009

Robotics
from fundamental research to market success

Machines that know what they do

Roland Siegwart
Autonomous Systems Lab
ETH Zurich

Autonomous Systems Lab

ETH Zürich

Outline

- Introduction
  - Challenges and Hurdles
  - The Key Message
- The R&D Challenges
- Examples
  - RoboX
  - Inspection Robotics - AIR
  - Visual Mapping
  - Container Robot
  - KIWA Systems
- Technology Transfer through Spin-Off Companies
- Future Avenues
  - Most Promising Fields
  - What Society wants

Challenges and Hurdles

- Tow metrics for measurement of success
  - University research is measured by **publications and impact factors**
  - Industry is measured by **market success**
- Two kinds of key collaborators
  - Universities have the **crazy people** that thinking out of the box but lack experience
  - Industry **experienced and highly specialized** people with some blindness for new developments
    -> "we already tried it 10 years ago, it did not work"
- Difference in working environment
  - University have a fast turnover of collaborators
    -> **Loss of knowledge**, re-inventing the wheel
  - Industry has (should have) long-term collaborators
    -> **little incentives to take risks**

Challenges and Hurdles

- Different Time scales
  - University: 10-30 years horizon
  - Industry -> 2-3 years to market

- Innovation is 10% inspiration and 90% transpiration
  - Universities **prefer inspiration**
    -> but transpiration can also be very rewarding, because it will drive you to market success
  - Industry **forgets about the inspiration** because of continuous transpiration

Research and Industry Drifting Apart

- Each side is optimizing towards their main measure of success

Short term benefit

Long term investment in new technologies

Key Message

- Keep it simple
  - "*One should keep things as simple as possible - but not simpler!*" (A. Einstein)
  - Robustness increases with simplicity
- Technology transfer
  - Transferring novel technologies is about „transferring" the enthusiastic people behind it
- Don't solve virtual problems
  - even if they are probably more rewarding according to university success metrics

The R&D Challenge

Seeing , Moving, Feeling, Understanding

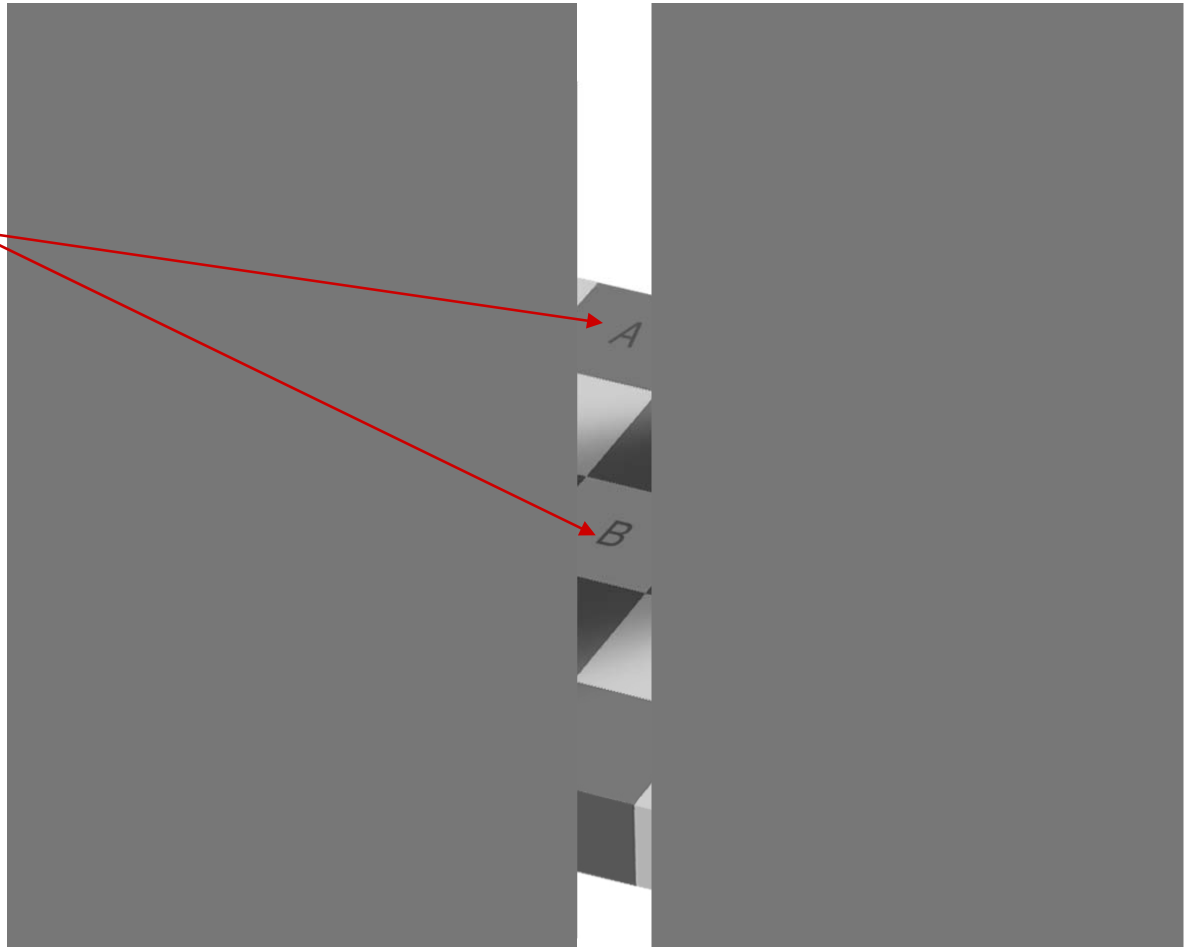
Autonomous Systems Lab

ETH Zürich

"Seeing" the world – more than appearance

- Perception and models ("understanding") are strongly linked

What is the difference in brightness?



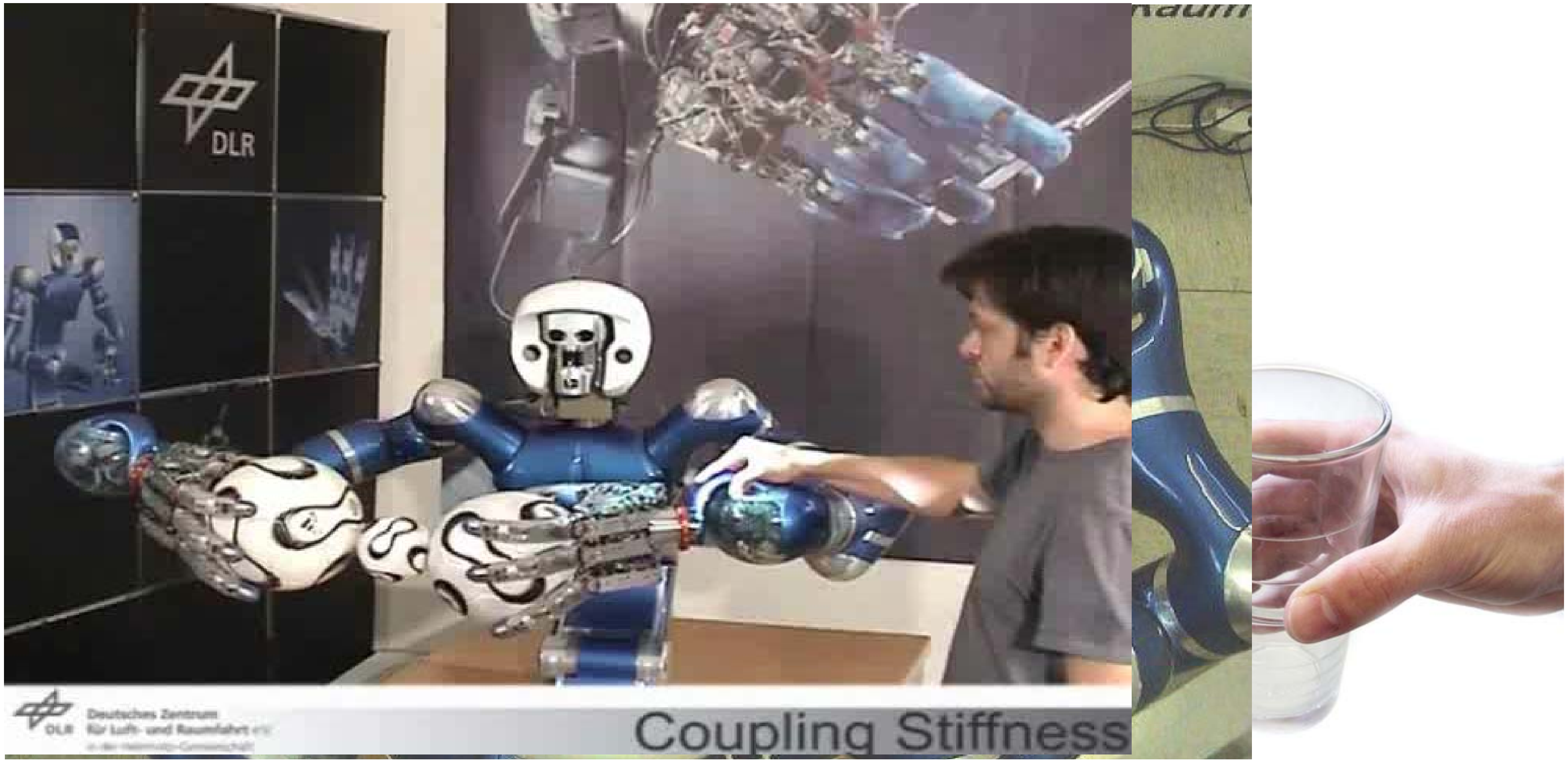
http://web.mit.edu/persci/people/adelson/checkershadow_downloads.html

"Moving" - Intelligent Designs

- Passive locomotion concept
- 6 wheels
  - two boogies on each side
  - one fixed wheel in the rear
  - one front wheel with spring suspension
- length: 60 cm
- height: 20 cm
- Characteristics
  - highly stable in rough terrain
  - overcomes obstacles up to 2 times its wheel diameter

"Feeling" the world

- Tactility, key for controlling the real world

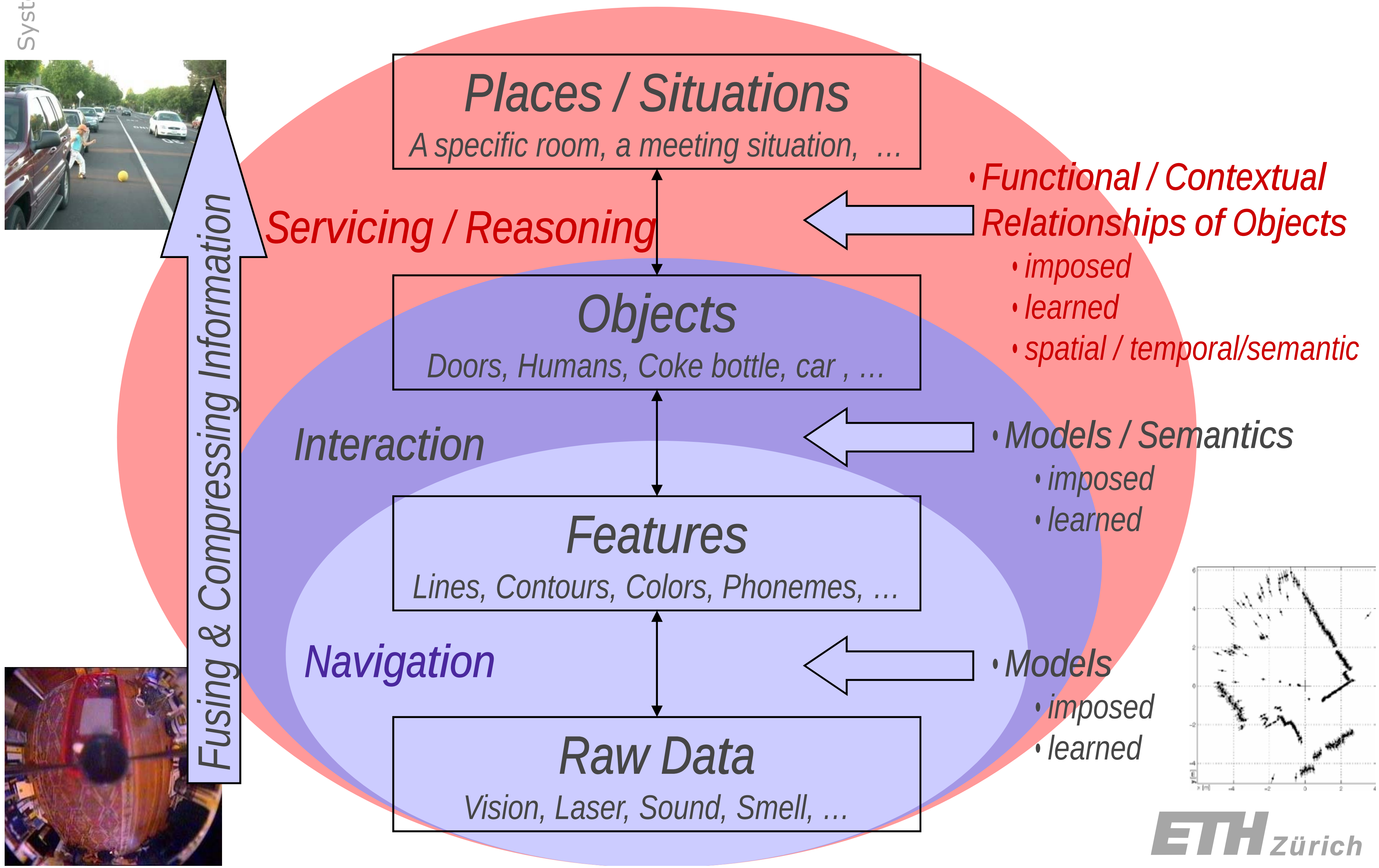


Courtesy of Albu-Schaeffer & Hirzinger, DLR, Germany

- It takes us around 14 years
  to learn holding a glass with an optimal force

Systems Lab

"Understanding" the world



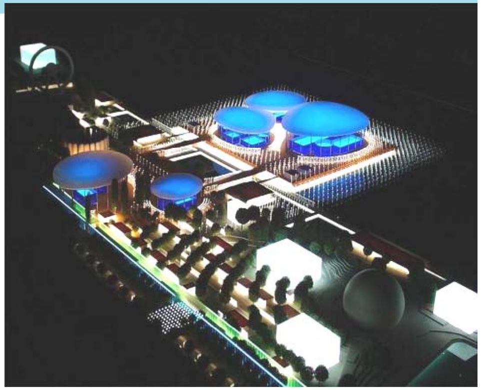
ETH Zürich

The way forward

- Perceive and understand the environment
  - Robots that know what they do
- Design of robot systems
  - Robots that are best adapted to the task and their environment

Examples

EXPO.02 Large Installation of Autonomous Tour-Guide Robots



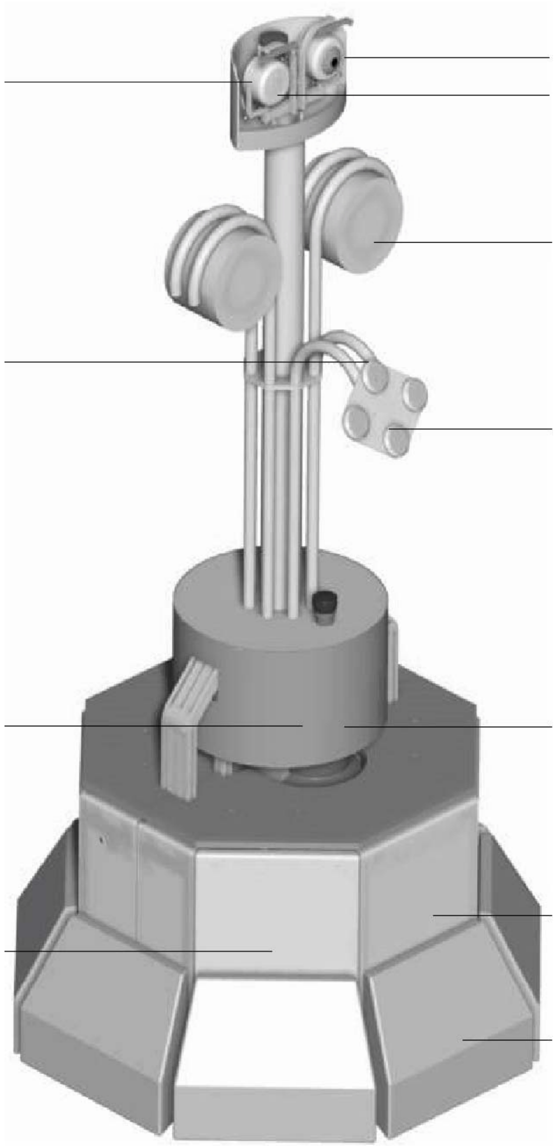
- Facts and Figures (May 15 – October 20, 2002)
  - Fully autonomous navigation and interaction in human cluttered environment
  - 11 robots
  - 12 hours per day
  - 159 days of operation
  - Operational time: 13,313 hours
  - Number of visitors: 686,000
  - Total travel distance: 3,315 km
  - navigation reliability nearly 100%

Robot Design



- Functional Design
- Humanoid appearance only if it is necessary for the functionality

Robox: The Functionalities



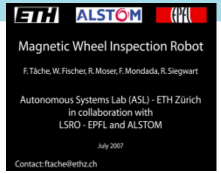
11 RoboX @ expo.02

56 s

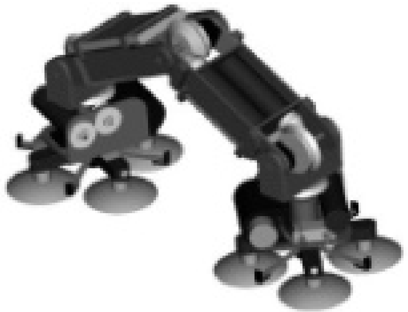
Implementation

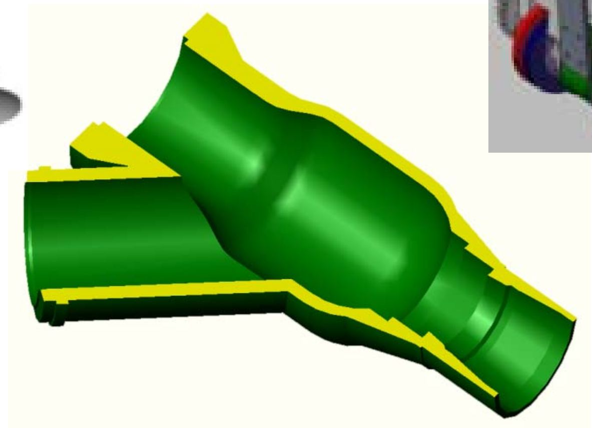
- 1997-2000
  - Basic research in navigation
- 2000
  - First Prototype developed by EPFL
- 2001
  - Creation of BlueBotics
- 2002 Implementation at expo.02
- 2009
  - BlueBotics has around 10 collaborators

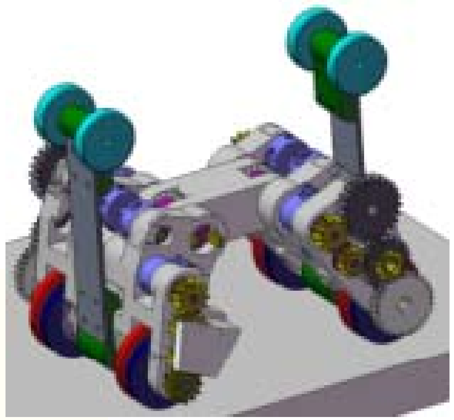
Inspection Robots

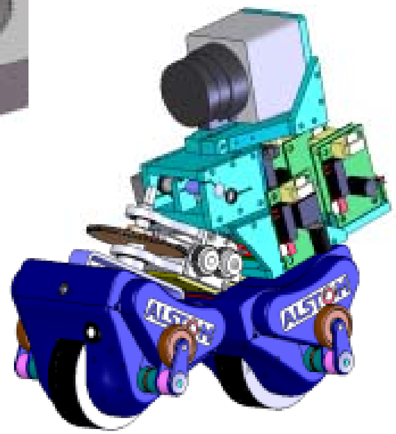


- Inspections of Power Plants are very costly:
  - down-time represents losses of millions per day
- Robotics technology impotently reduces down time:
  - Preventive Maintenance
  - Access without disassembly







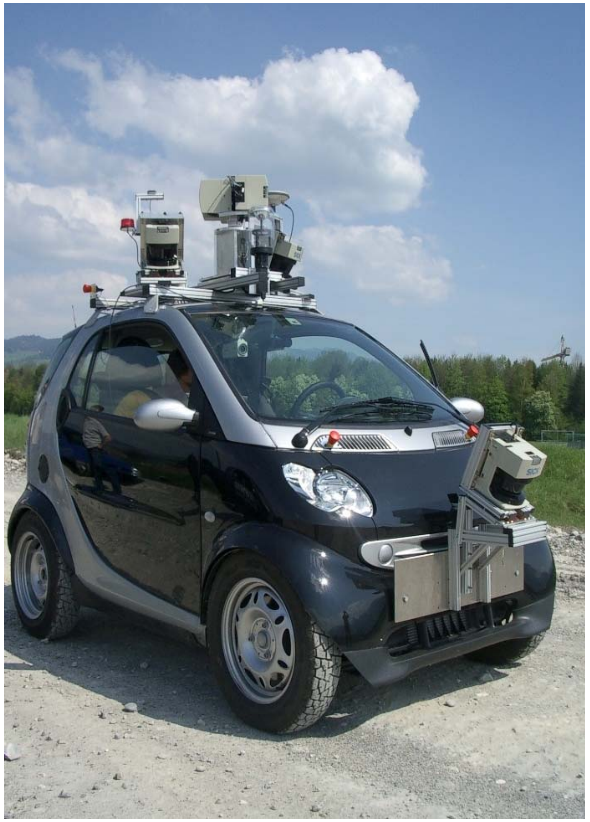


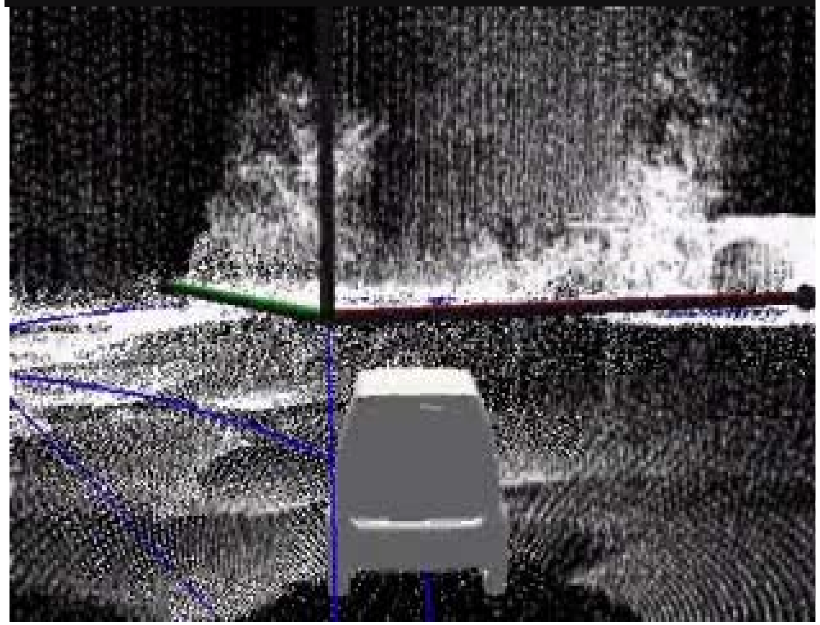
In collaboration with ALSTOM

Implementation

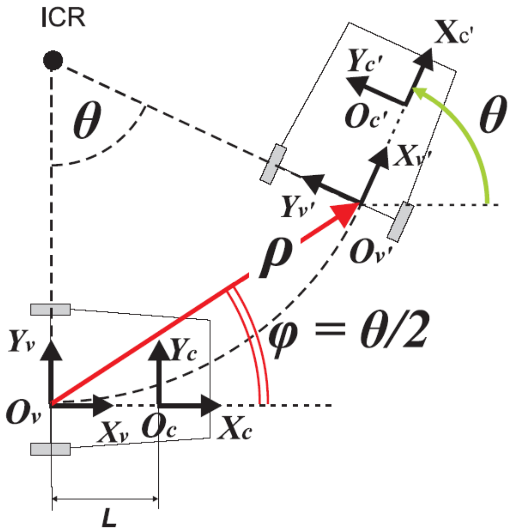
- 2005:
  - Precursor pre-study (mandate of ALSTOM)
- 2006 (fall):
  - ALSTOM Inspection Robotics (AIR) founded by ALSTOM and ETHZ;
  - today around 10 people
- 2007:
  - Start of CTI project, now ~ 12 people involved
- 2008-09:
  - New ad-hoc mandates (camera com. ….)
- 2008 (fall):
  - CTI-extension to "multi robot‟; additional funding from ALSTOM; collaboration with MIT
- 2010:
  - EU Project on "flying inspector" ?

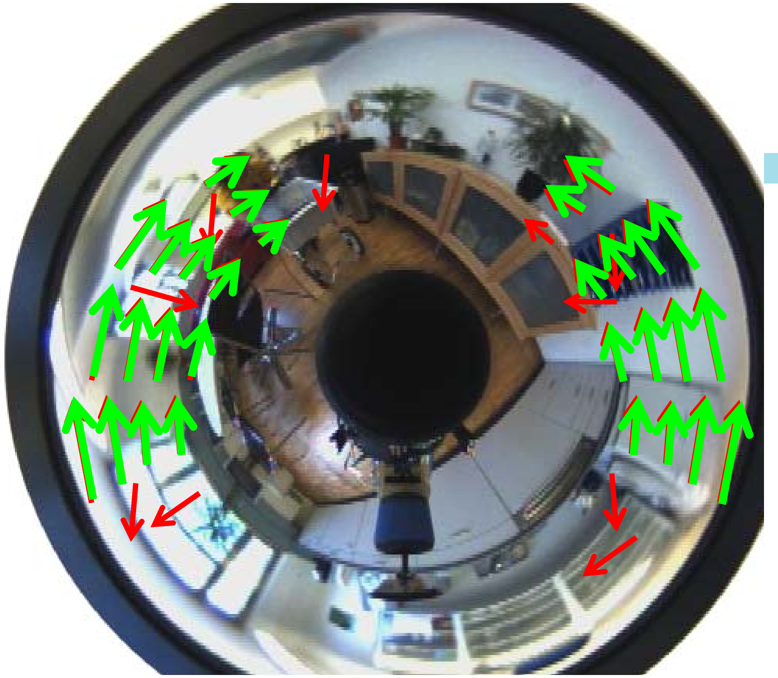
Autonomous Driving

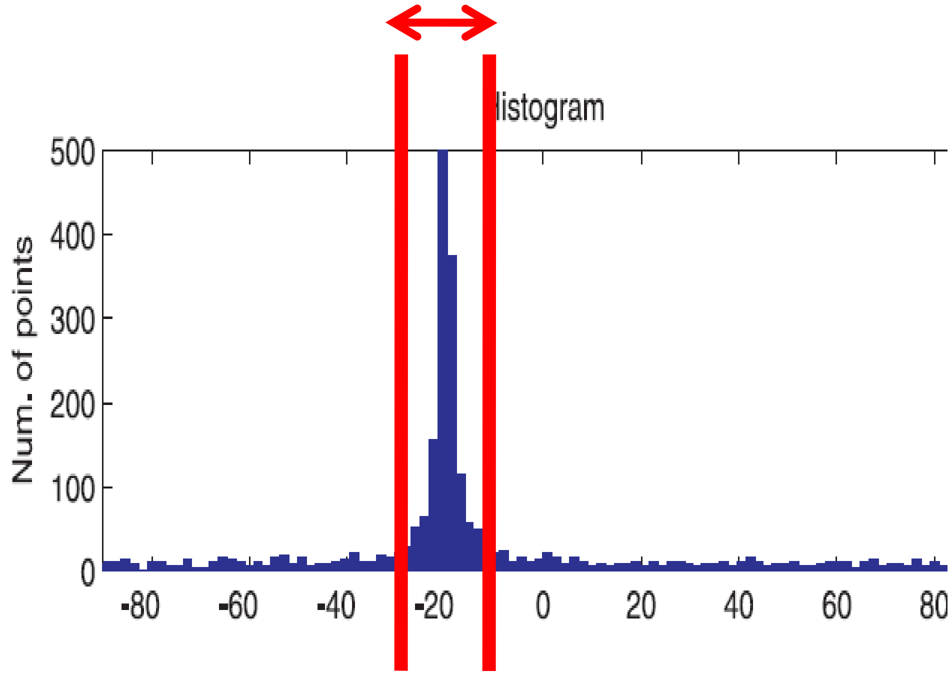




1-Point RANSAC







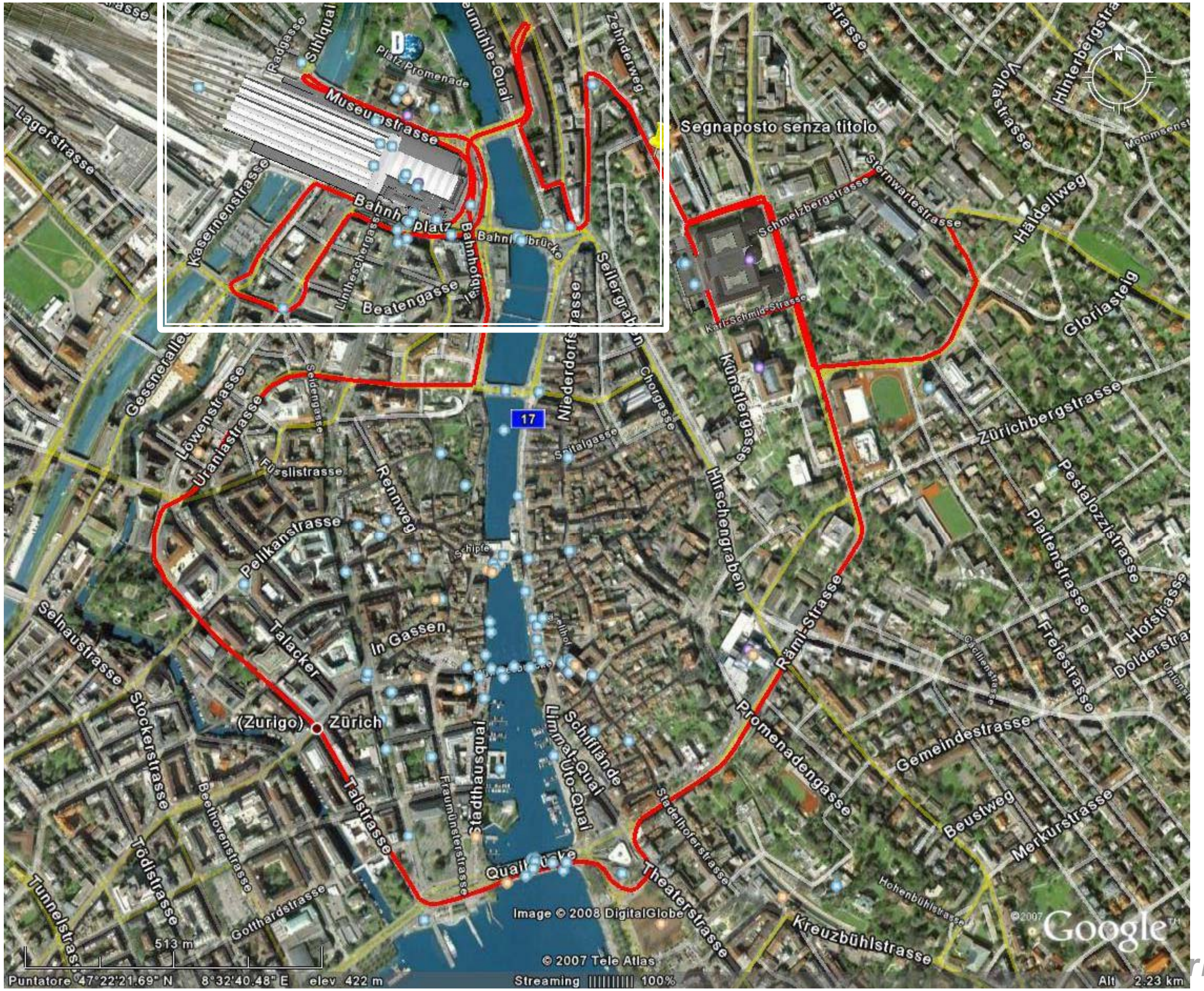
- Numb. of iterations = 1
- The most efficient algorithm for removing outliers
- Runs to 800 fps!

[Scaramuzza, ICRA'09]
[Scaramuzza, ICCV'09]

Autonomous Systems Lab

Visual Odometry

Davide Scaramuzza

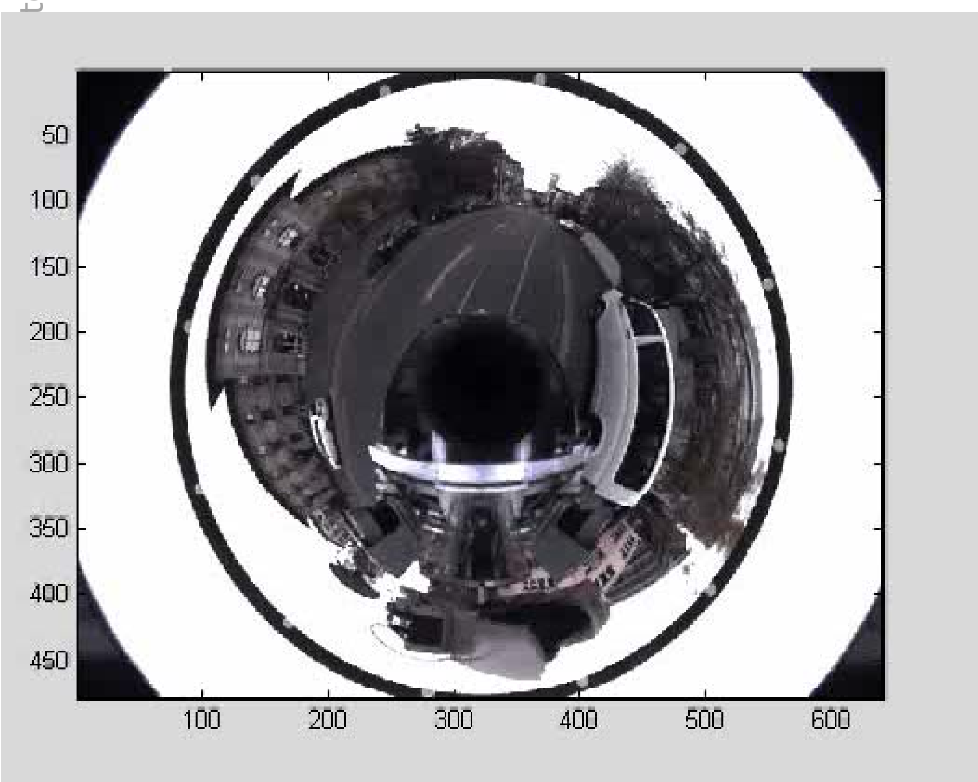


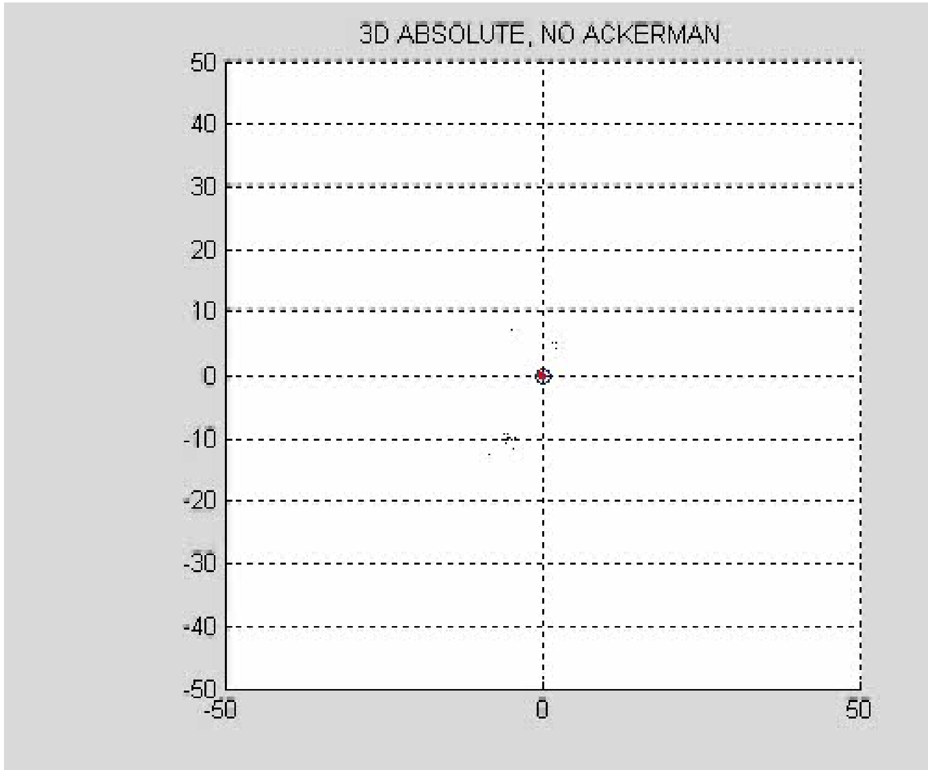
F

rich

Visual Odometry

Davide Scaramuzza

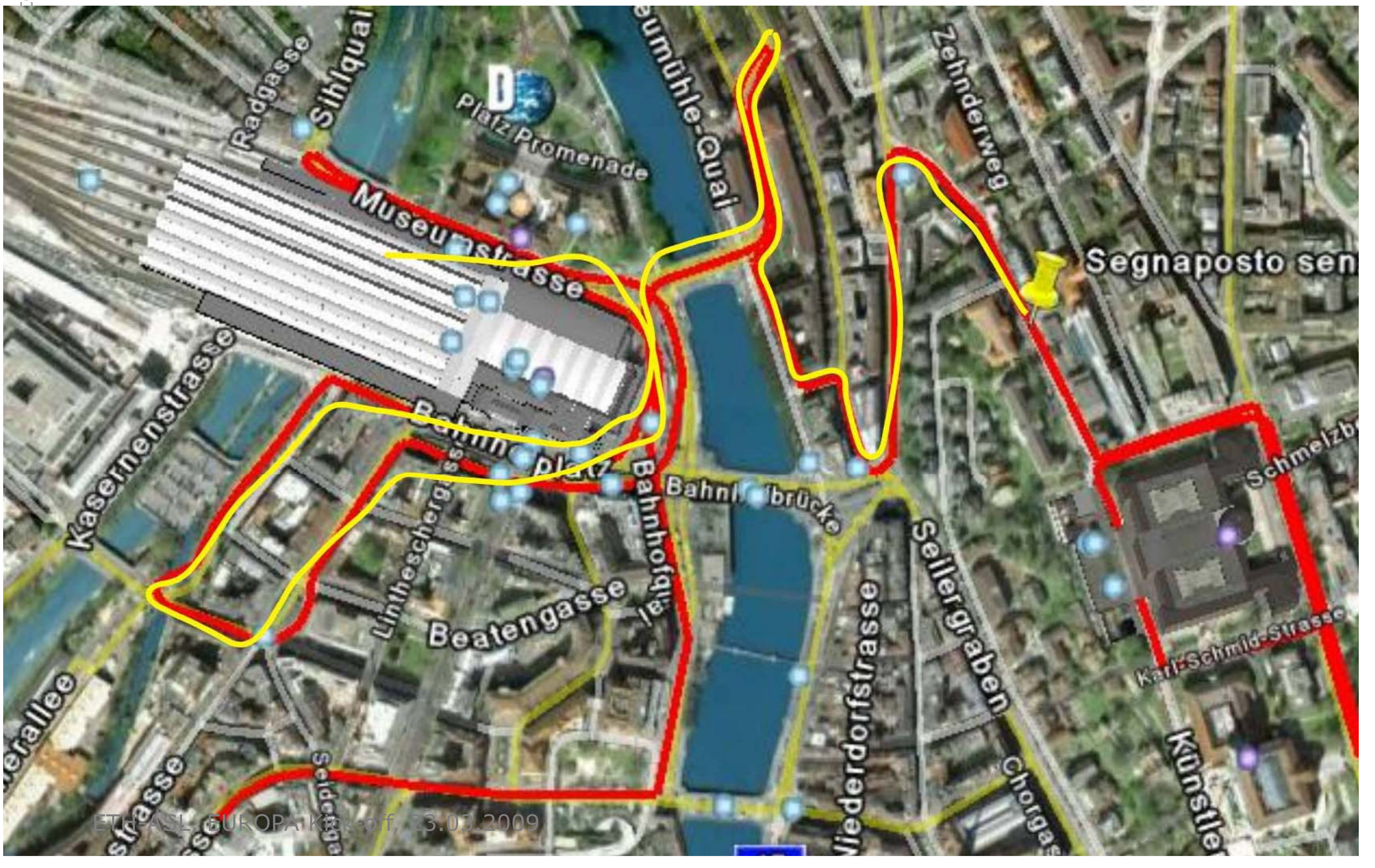




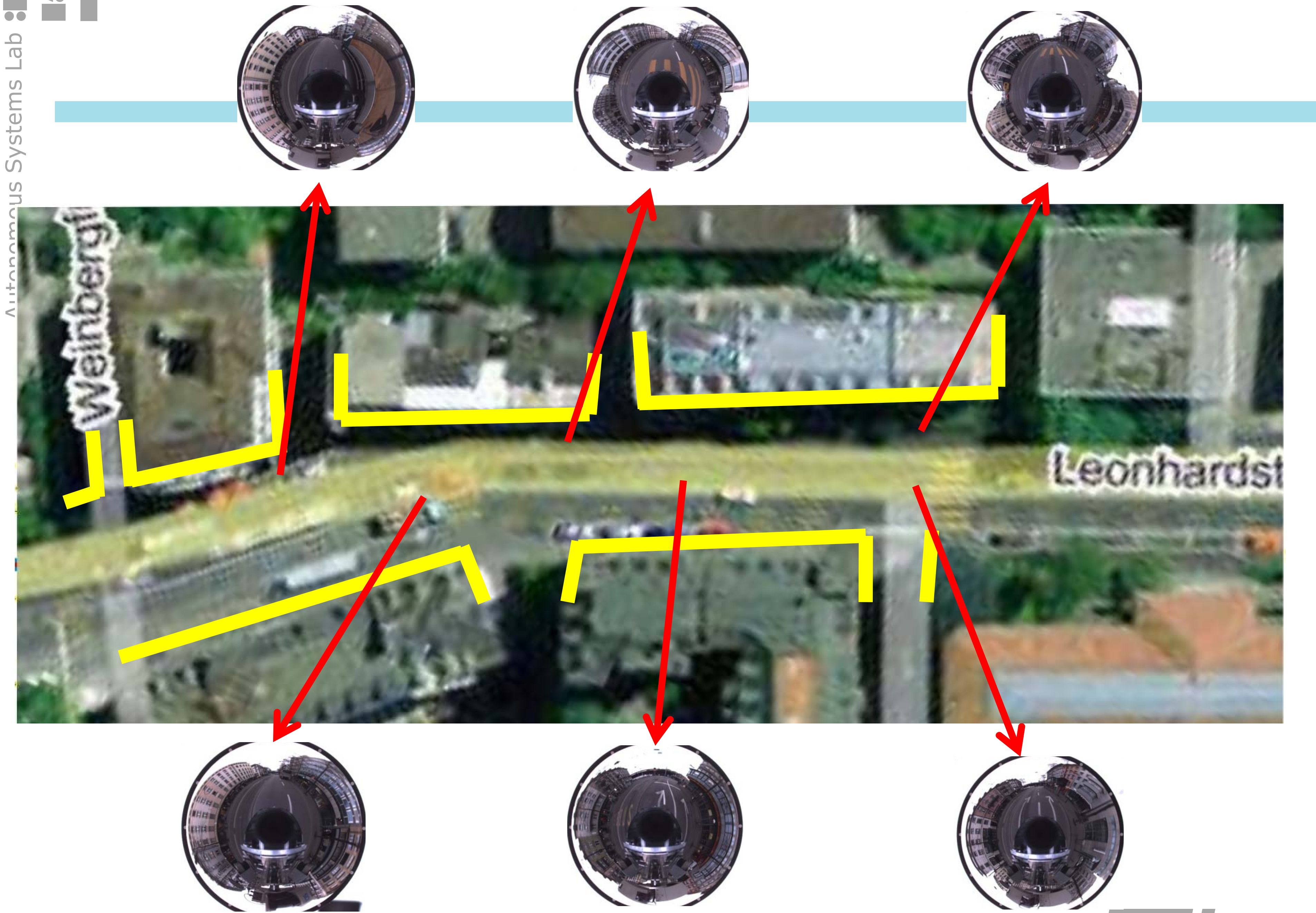
- The video shows a 3 Km path recovered using only point features and the car speed for the scale
- In the real case the algorithm works even faster than this video (without feature extraction) thanks to the usage of *vehicle motion model*

State of the Art - Visual Odometry

Davide Scaramuzza



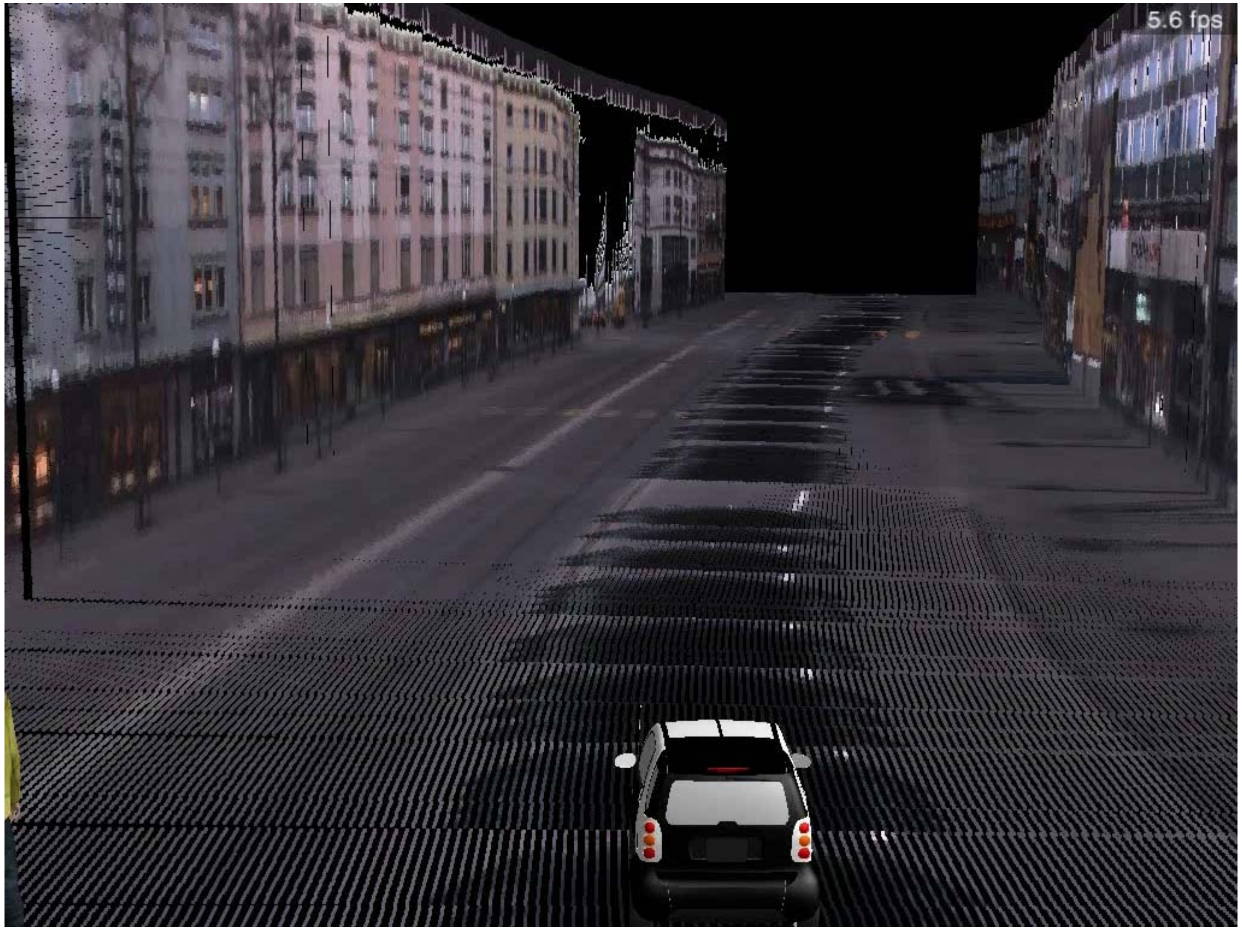

Weinbergl
Leonhardst



3D Models built from Point Clouds and Images

Lowenstrasse, Zurich

3D Models built from Point Clouds and Images



Implementation

- In preparation
- Technology to be used in various R&D projects

Supply Chain Distribution: Big Business & Big Problem

www.KivaSystems.com

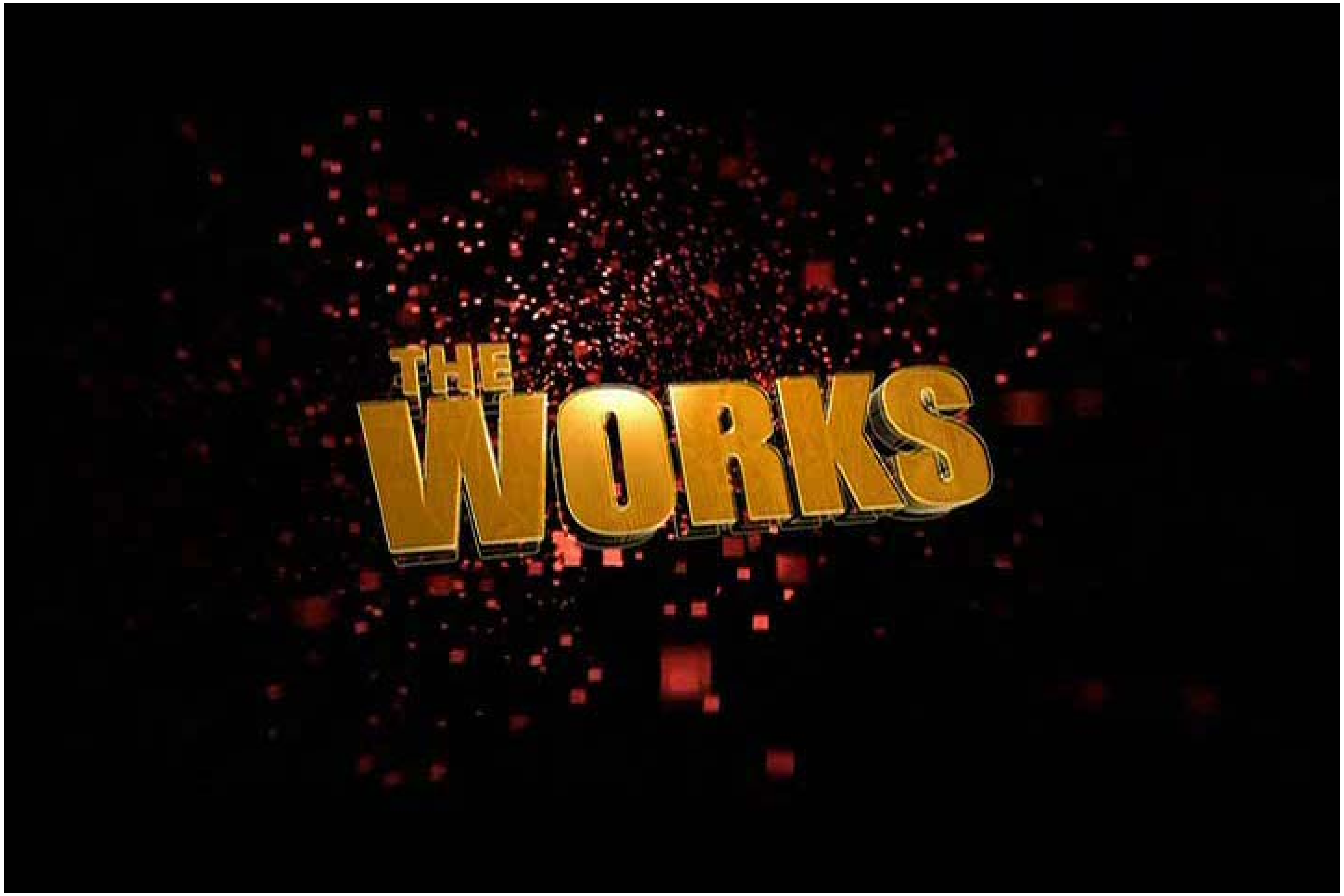
1. Order received.
2. Somehow the correct items are located and picked. Extremes:
   a) Workers move to locate and pick items.
   b) Fixed structure automation: sorters, conveyers, carousels:

3. Order is delivered.

Courtesy of Raff D'Andrea, ETH & KIVA Systems

KIVA Robots at Work

www.KivaSystems.com



Excerpt from History Channel, 2008

KIVA Robots System

www.KivaSystems.com

- Design Philosophies
  - shift **complexity from hardware to software**: cost & flexibility
  - hierarchical, modular system: isolate complexity & verifiability
  - communication failures degrade performance, but not stability
  - **robustness** for safe operation, adaptation for performance

- Key enabling technologies
  - Inexpensive sensors
  - Inexpensive computation
  - Inexpensive wireless communication
  - Take advantage of all these technologies

KIVA Systems: Implementation

www.KivaSystems.com

- KIVA Systems - Facts and Figures
  - 2003
    - Founded
  - 2005:
    - Revenue $ 0.2 million
  - 2008:
    - Revenue $ 21.4 million
    - 120 Empoyees
  - Today:
    - Around 10 installations with up to 1000 robots

    - http://www.inc.com/inc5000/2009/company-profile.html?id=200900060

AutoStrad®: Autonomous Containers Handling

www.patrick.com.au/ ; www.acfr.usyd.edu.au/

- Container Handling
  - Simplest outdoor field robotics application
  - Structured environments, well defined tasks

- General Requirements
  - Productivity equal to manned vehicles
  - Safe, efficient port interface
  - Non-increasing maintenance skills and costs
  - Flexible and incremental deployment

Courtesy of Hugh Durrant-Whyte, University of Sidney

AutoStrad Platform

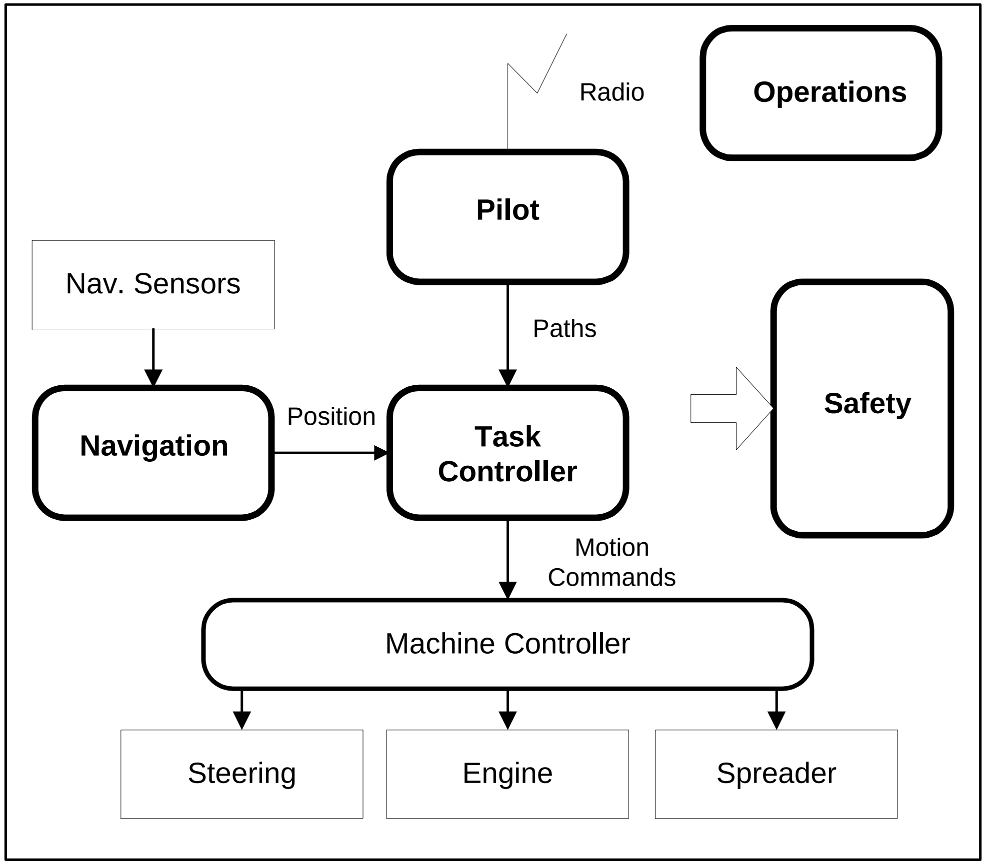
www.patrick.com.au/ ; www.acfr.usyd.edu.au/

- Comparable to manned straddle
- Proven 24/365 fully autonomous operation
- Specification:
  - 65 tonnes
  - 10m high
  - 3.5m wide
  - 9m long
  - Loads to 50 tonnes
  - Speed to 30kmph
- Diesel-electric drive
- Hydraulic steer and hoist

Technical Innovations

www.patrick.com.au/ ; www.acfr.usyd.edu.au/

- Earlier work on FRAIT vehicle drove four technical innovations:
  1. High integrity navigation system design
  2. Mm-wave radar navigation technology
  3. Large vehicle modelling
  4. Safety system design



AutoStrad Platform

www.patrick.com.au/ ; www.acfr.usyd.edu.au/

- AutoStrad is the most advanced large-scale autonomous vehicle in commercial application
- Product success due to:
  - Four **key technical innovations** for autonomous systems
  - **Strong collaboration** between end users, equipment suppliers and technology developers
  - Staged development based on **sound systems engineering principles**

AutoStrad Implementation

- 1997 – 2003
  - Development by ACFR, University of Sidney
- 2005
  - Proven successful commercial operation starting
- 2009
  - Around 50 robots in operation
- Market Size
  - 150 units in Australia
  - 1,200 units world-wide

PATRICK Technology & Systems

Kalmar Industries

35%

Toll Holdings/
Patrick Terminals

50%+1

Inventors

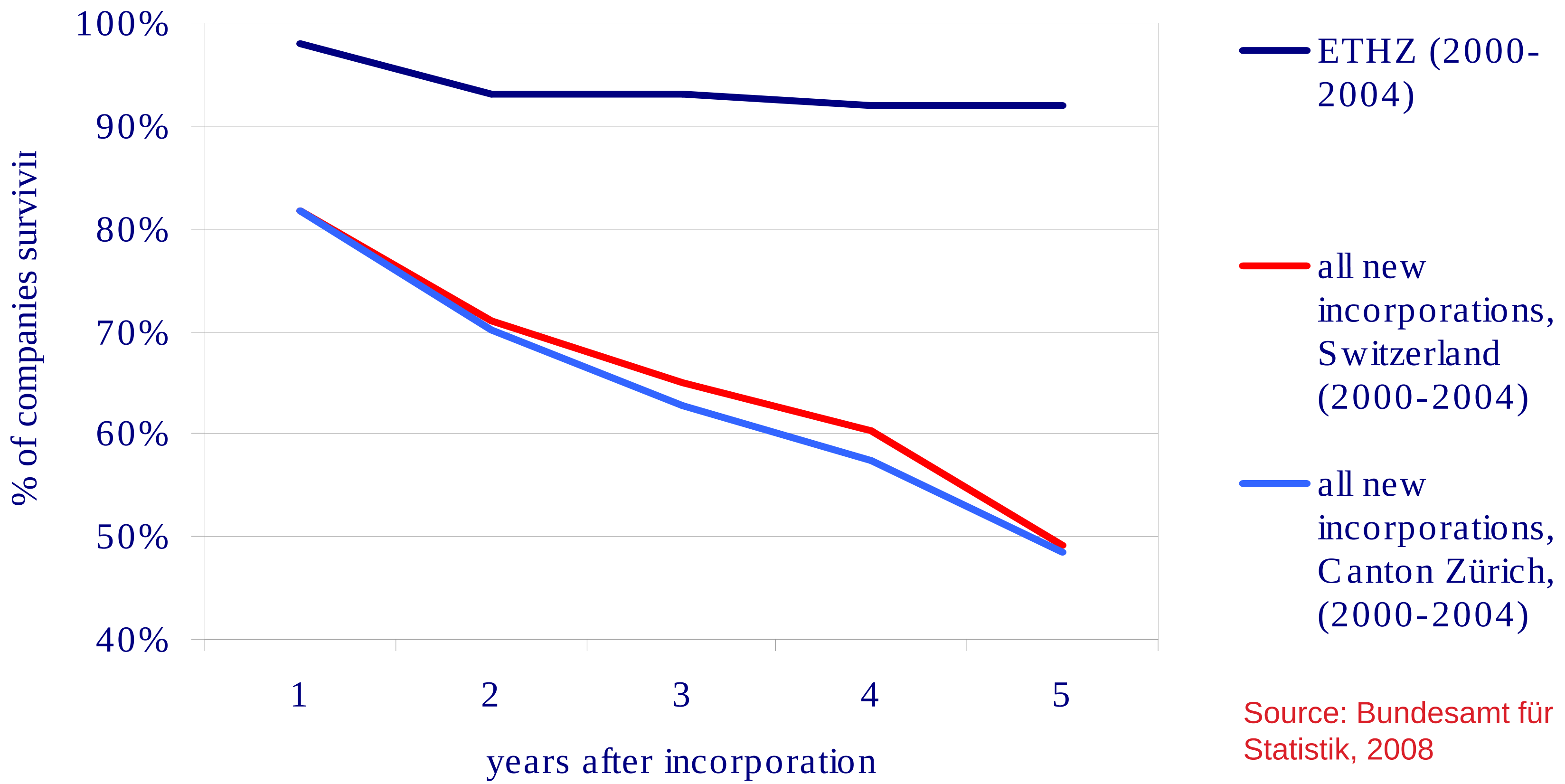
15%

Technology Transfer

Autonomous Systems Lab

ETH Zürich

Spin-Offs / Start-Ups: Survival Rates



Source: Bundesamt für Statistik, 2008

- University Spin-Offs create around 10-15 jobs each - but over a longer time-span
- Other spin-offs create only around 2-4 jobs

Spin-Offs: Equity raised

- Funding Gap at Seed/Start-up stage
  - 74% of Seed/Start-up equity is contributed by founders/FF
  - First Angel/VC round on average 2 years after start-up

Stage	Pre-seed	Seed/Start-up	Early	Expansion
Source	Founders/FF	Business Angels	Angels/VC	VC
Demand per round	$20-50k	$50-250k	$2000k	$5000k
Supply		Funding Gap		

ECHORD

Source: own survey, Sohl 2003, Library House 2007

Oportunities and Markets

Opportunities / Markets

- Entertainment
- Industrial Transportation
- Cleaning
- Medical robotics
- Office logistics

The coffee servant
Nesspresso / Bluebotics, Switzerland

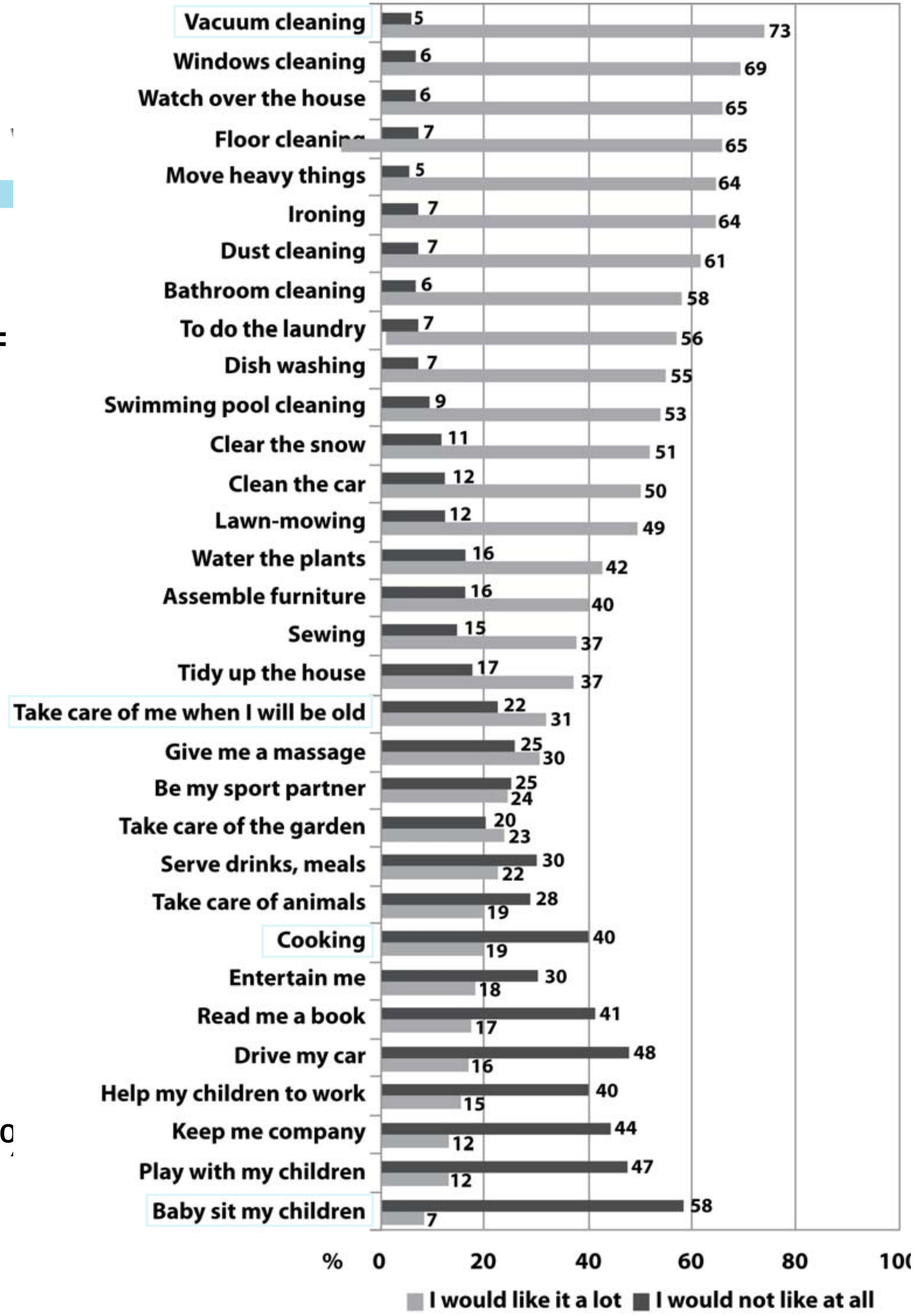
- Construction, mining
- Farming
- Rescuing, fire fighting, surveillance
- Industrial services

- Health and elderly care
- Services in private and public places

Service Robot
ETH President greeting ASIMOV, Honda Inc.

What people really

- Sample Characteristic: N =
- Gender
  - Male 51%
  - Female 49%
- Age
  - 10-20 15%
  - 20-40 31%
  - 40-65 43%
  - 65+ 6%
- Education Level
  - No education 3%
  - In education 11%
  - Apprenticeship degree 13%
  - Vocational school degree 29
  - University degree 35%
  - Other 9%



Entry Point: Elderly Care

- Human Washing Machine from Sanyo
  - $ 50’000

  - Several elderly women say they enjoy their robotic baths because of the privacy it offers over in-house nursing.

Take Home Message

- Keep it simple
- Go for scientific excellent
- Don‘t solve virtual problems
- Be patient, go for the fields where you see a clear opportunity
- Technology transfer equals people transfer
- Market success is very rewarding, also for academics

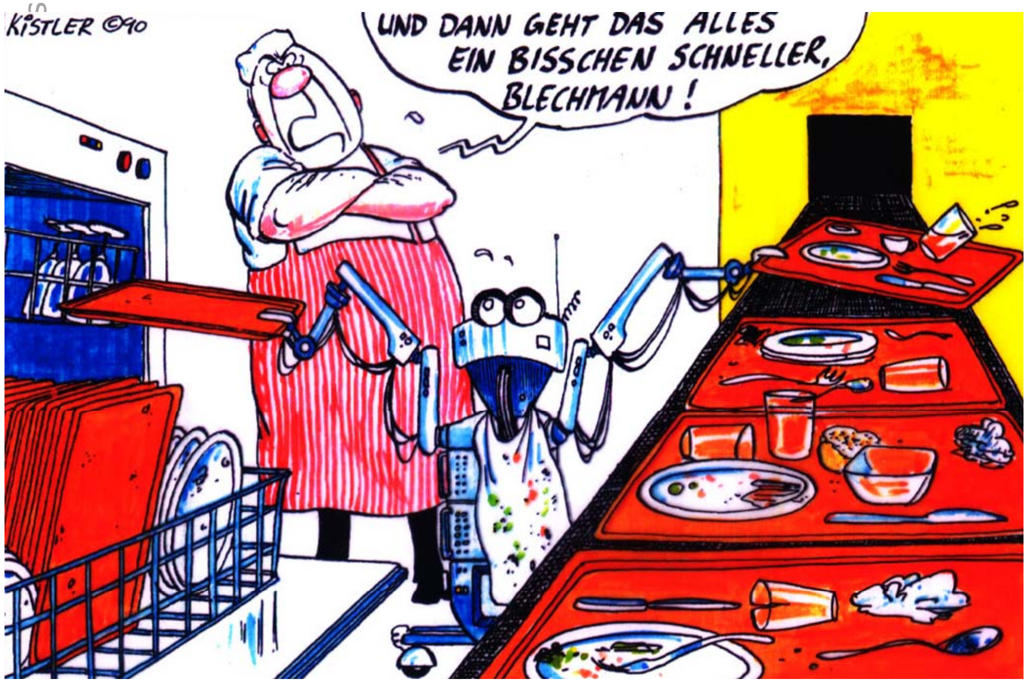
Take Home Message

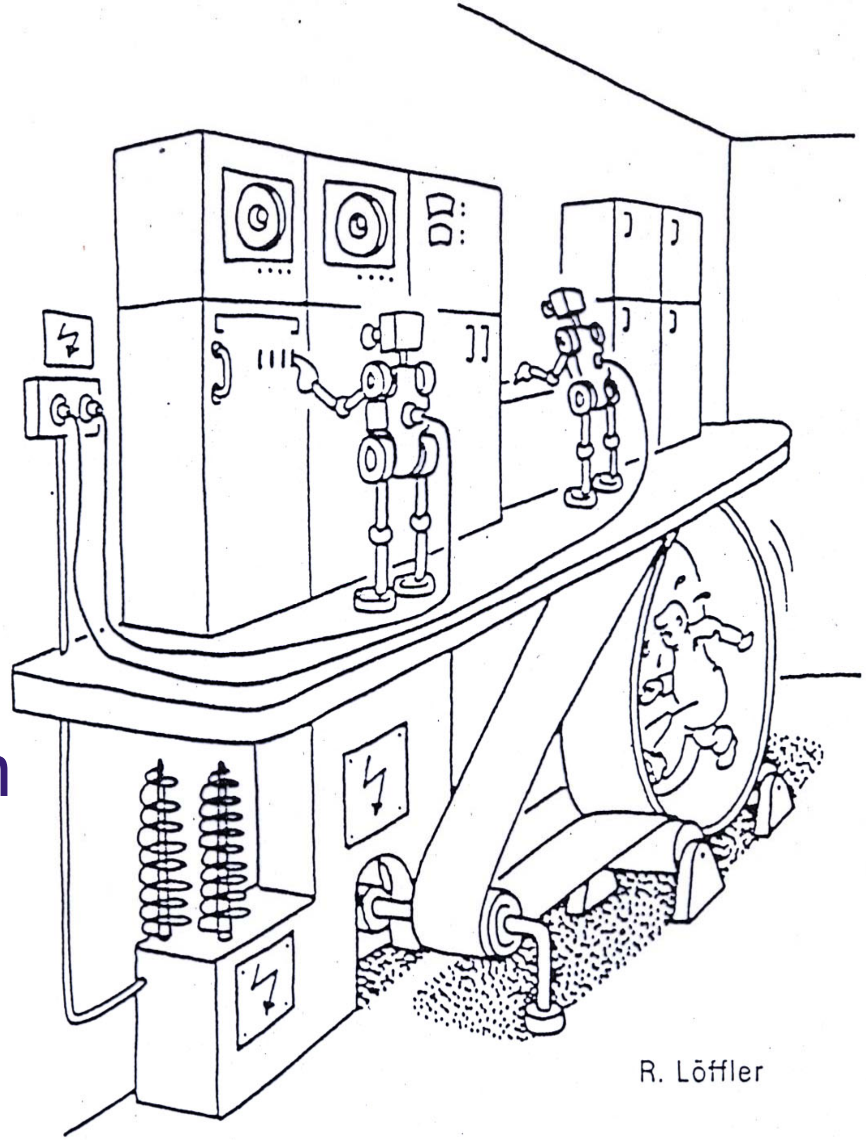
- Innovation needs **outstanding engineers** that are ready to go the hard, but rewarding way up to the market

- The transfer of new technology from the lab to the market needs **„seed funding“** that is easily accessible

→ **ECHORD** is tool for doing so

Towards a bright future





Thank you for your attention