Research Project Proposal: Physics from Vision for Robotic Grasping

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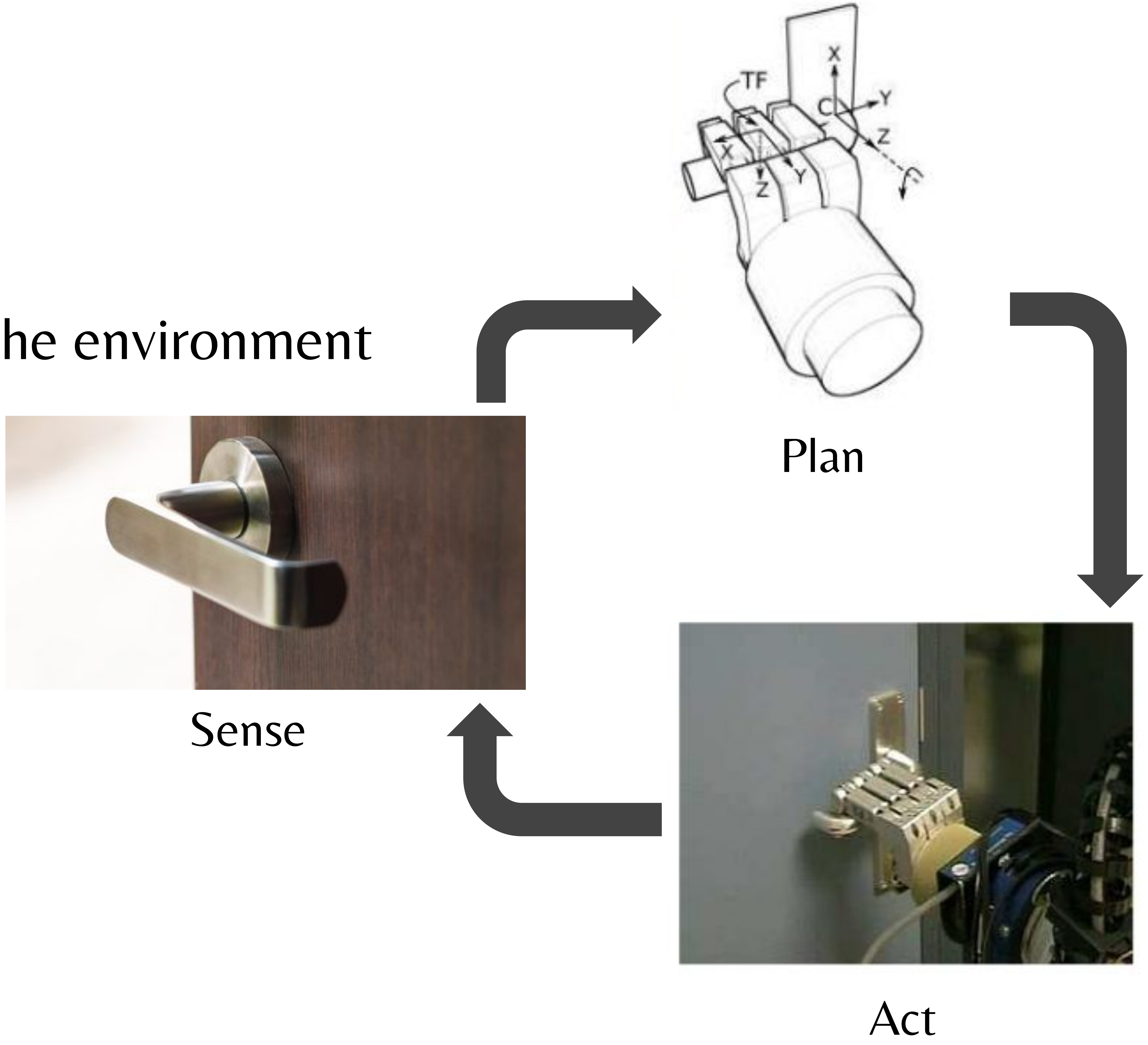
HONOURS PROGRAMME HP-SR in Information Technology

Autonomous Robots

- **Sense**: acquire and model data about the environment
- **Plan**: select the course of action
- **Act**: perform each planned action



Affordances

Affordances

Emergent **properties** embodied in the **relations** between an animal and its environment directly connected with the **possibility of action** of the animal with the environment

Michaels, C. Affordances: Four points of debate. ECOLOGICAL PSYCHOLOGY 15 (04 2003), 135–148.

Robotic Grasping

- **Control** of some or all degrees of freedom of some object with a **hand-like physical actuator**

Levine et al. Learning hand-eye coordination for robotic grasping with deep learning and large-scale data collection, IJRR (2018)

Robotic Grasping

- **Control** of some or all degrees of freedom of some object with a **hand-like physical actuator**

- Uses:
  - Moving objects
  - Fixing objects
  - **Tool use**

Levine et al. Learning hand-eye coordination for robotic grasping with deep learning and large-scale data collection, IJRR (2018)

Task-oriented Grasping

Project Objectives

Model and perceive the information needed to understand the grasp:

- Object type
- Object physics
- Object affordances

Grasping: State of the Art

- Act:
  - Grasp evaluation *(well established)*
- Plan:
  - Grasp planning *(well established)*
  - Uncertain model grasp planning *(active)*
- Sense:
  - Task-oriented grasping *(open)*
  - Uncertain model task-oriented grasping *(open)*

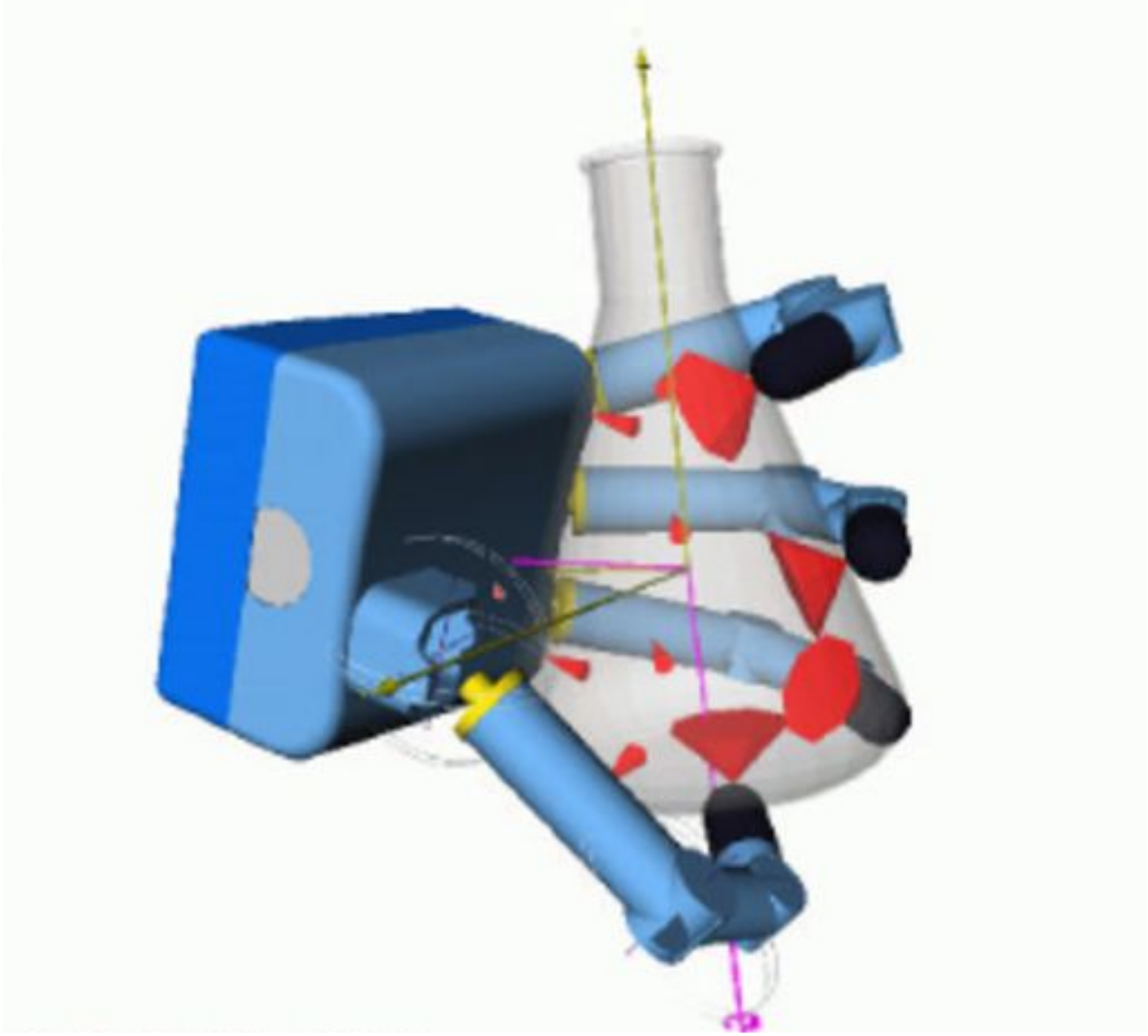
Grasping: Grasp Evaluation

- Grasp matrix: object twist to object twist on contacts
- Hand Jacobian: joint velocities to hand twist on contacts
- Contact models
  - Point without Friction: transmit only normal translational force
  - Hard finger: transmit all translational forces
  - Soft finger: transmit all translational forces and normal moments

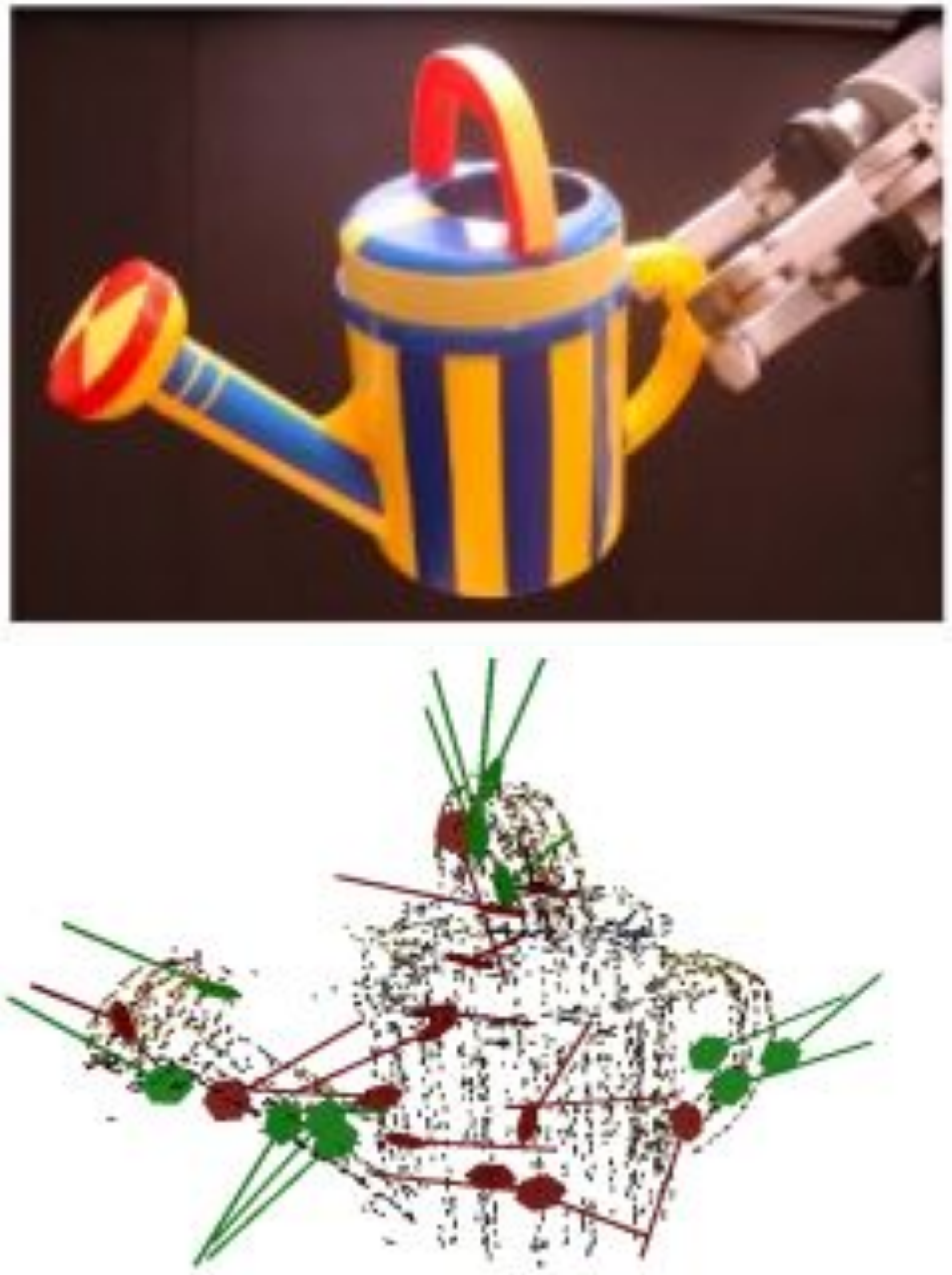
Dang et al. Tactile experience-based robotic grasping, HRI (2011)

Grasping: Grasp Planning

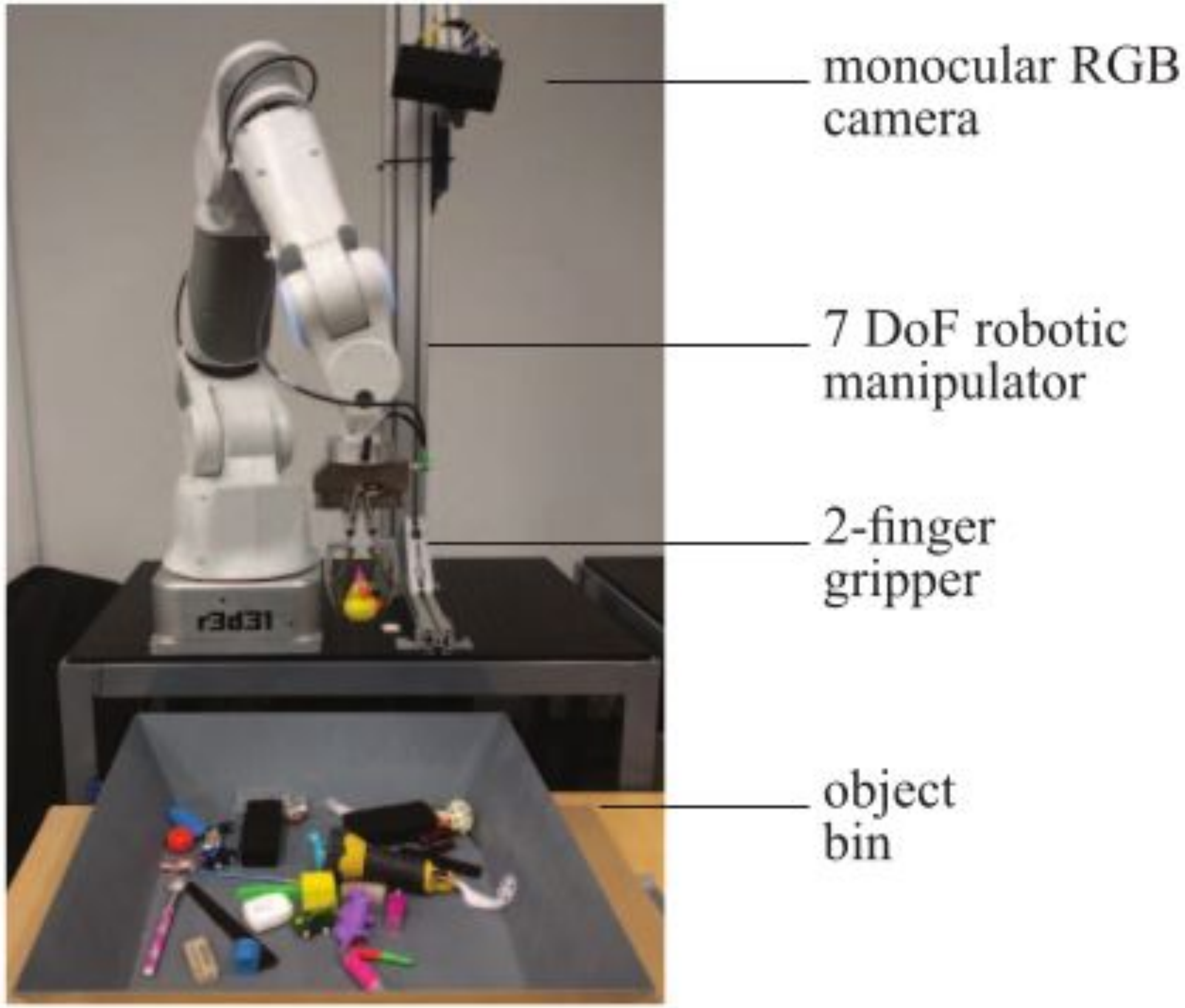
- Grasp planning: finding stable grasps, given object and actuator
- Needed input:
  - Contact points
  - Contact models
    - **Friction** at each point *(open problem!)*
- GraspIt! simulator collects a suite of tools for Grasp Planning



Grasping: Uncertainty in Grasp Planning

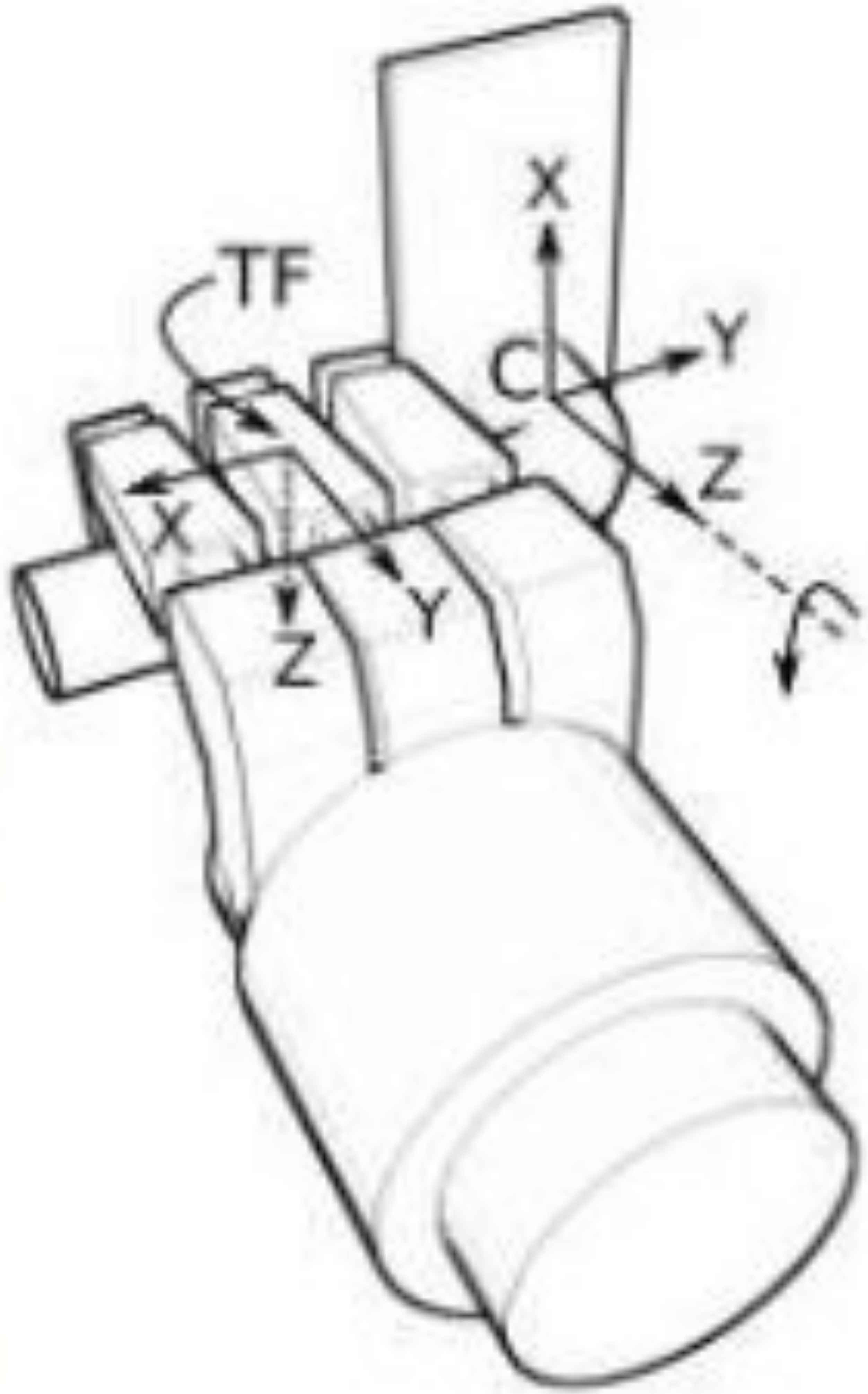


Erkan et al. Learning probabilistic discriminative models of grasp affordances under limited supervision, IROS (2010)



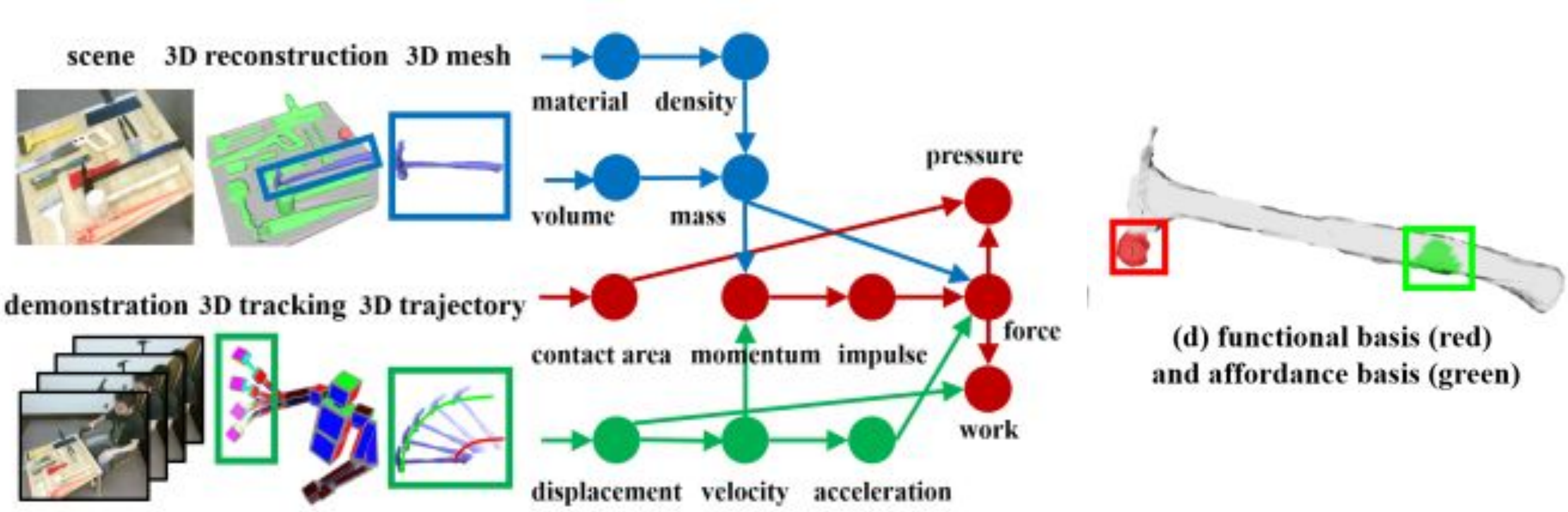
Levine et al. Learning hand-eye coordination for robotic grasping with deep learning and large-scale data collection, IJRR (2018)

Grasping: Task-oriented Grasping



Prats et al. Task-oriented grasping using hand preshapes and task frames, ICRA (2007)

Grasping: Uncertainty in task-oriented Grasping



Zhu et al. Understanding tools: Task-oriented object modeling, learning and recognition, CVPR (2015)

Unexplored opportunities

- Stated objectives:
  - Object type
  - Object physics
  - Object affordances
- Unexplored opportunities:
  - Physical framing of tasks and planning
  - Physical inference from vision

Overall project structure

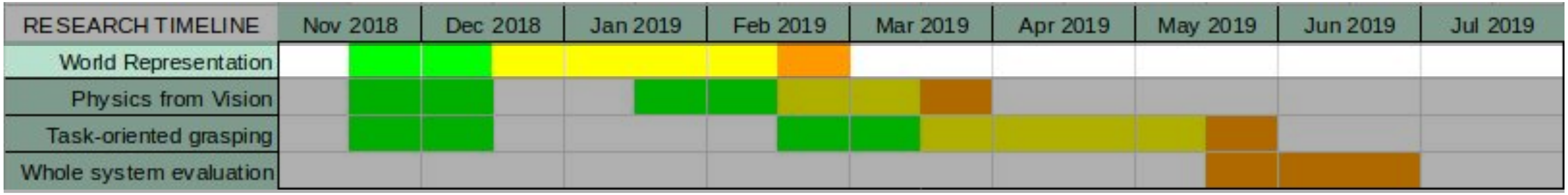
- **Task-oriented grasping**: plan grasps based on physics of objects and tasks
- **Physics from Vision**: infer physical quantities about the environment
- **World representation**: probabilistic representation of the environment

World representation

- Objectives:
  - Online 3D modeling of environment with uncertainty
  - Identify separate objects from background
  - Attach arbitrary knowledge to the model
  - Track rigid body motion

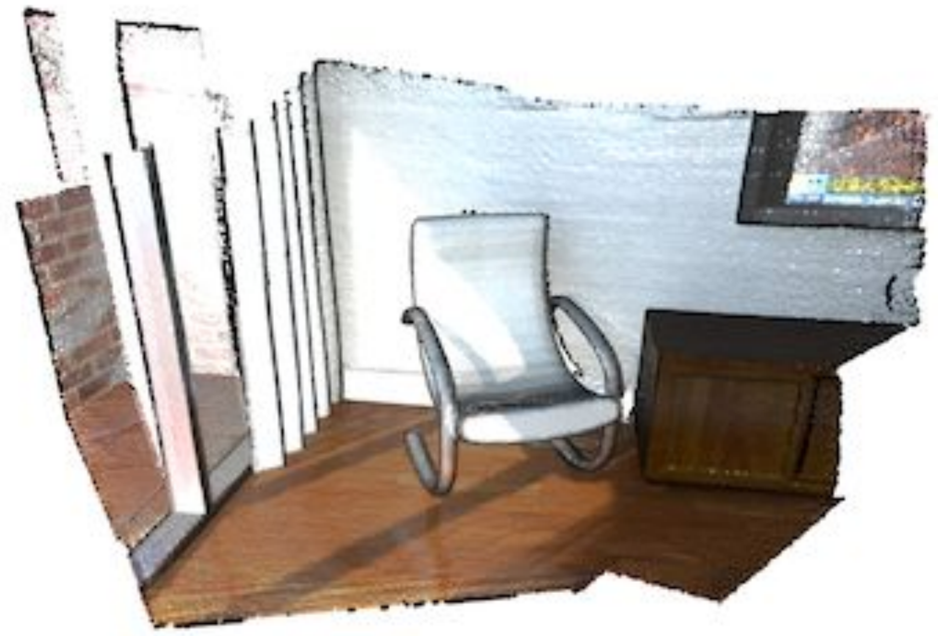
- Evaluation:
  - Full reconstruction of moving objects

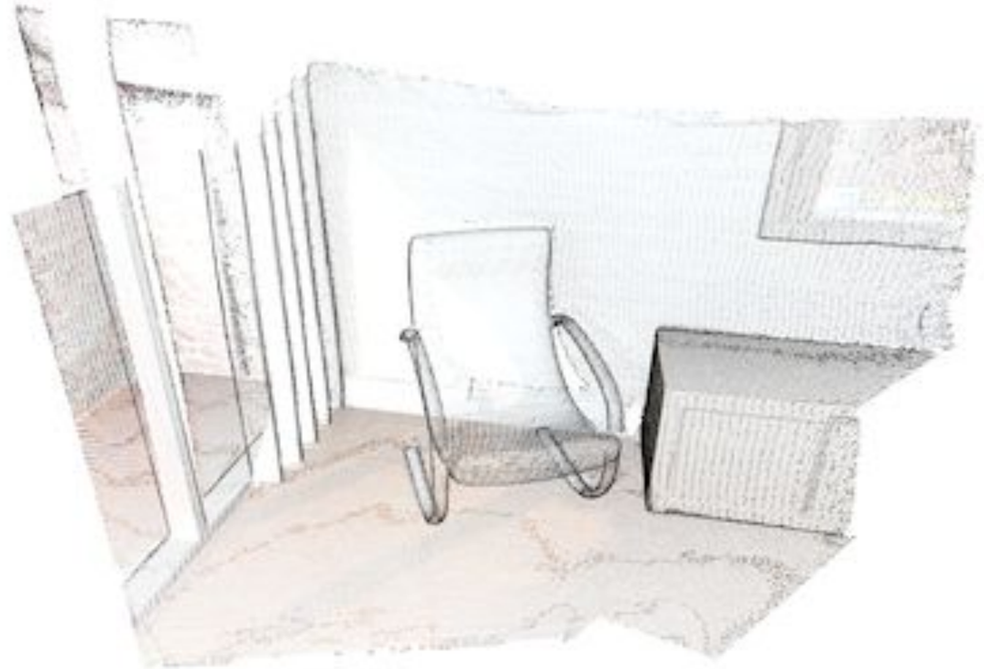
Images from www.open3d.org



World representation

- 3D reconstruction: RGB-D to pointcloud to mesh
- Uncertainty model: mesh points are multivariate gaussians
- Online update: successive pointcloud samples update mean and variance of nearest mesh points
- Movement tracking: visual features (like SIFT)





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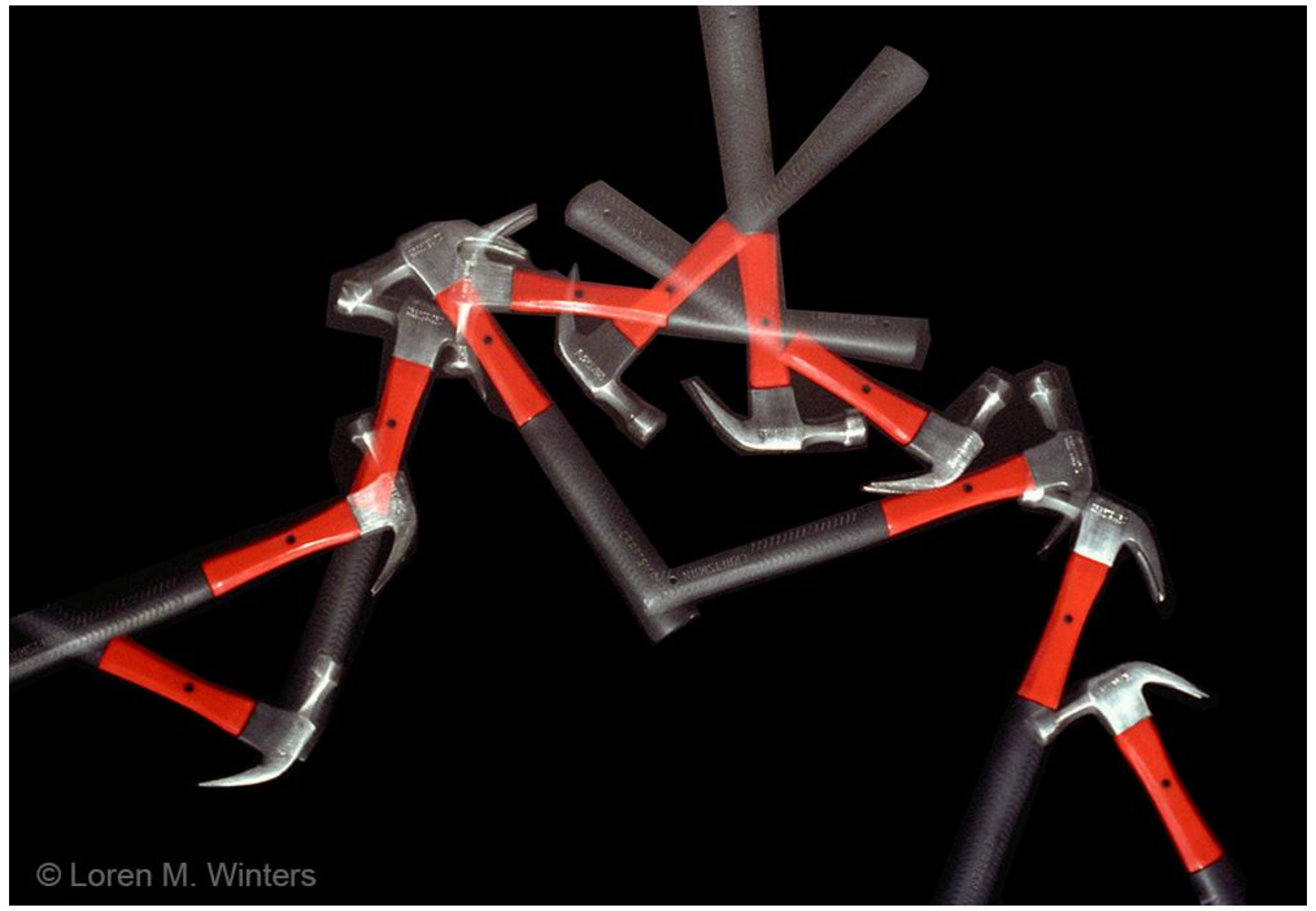
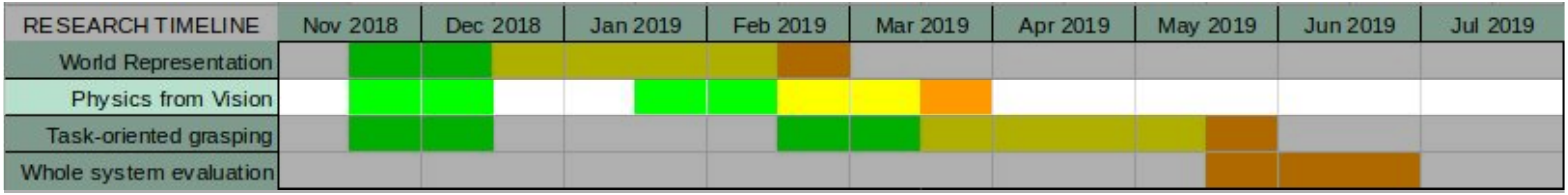
Physics from Vision

- Objectives:
  - Online estimation of Degrees of Freedom (DoF)
  - Online estimation of Center of Mass (CoM)
  - Estimation of surface material properties

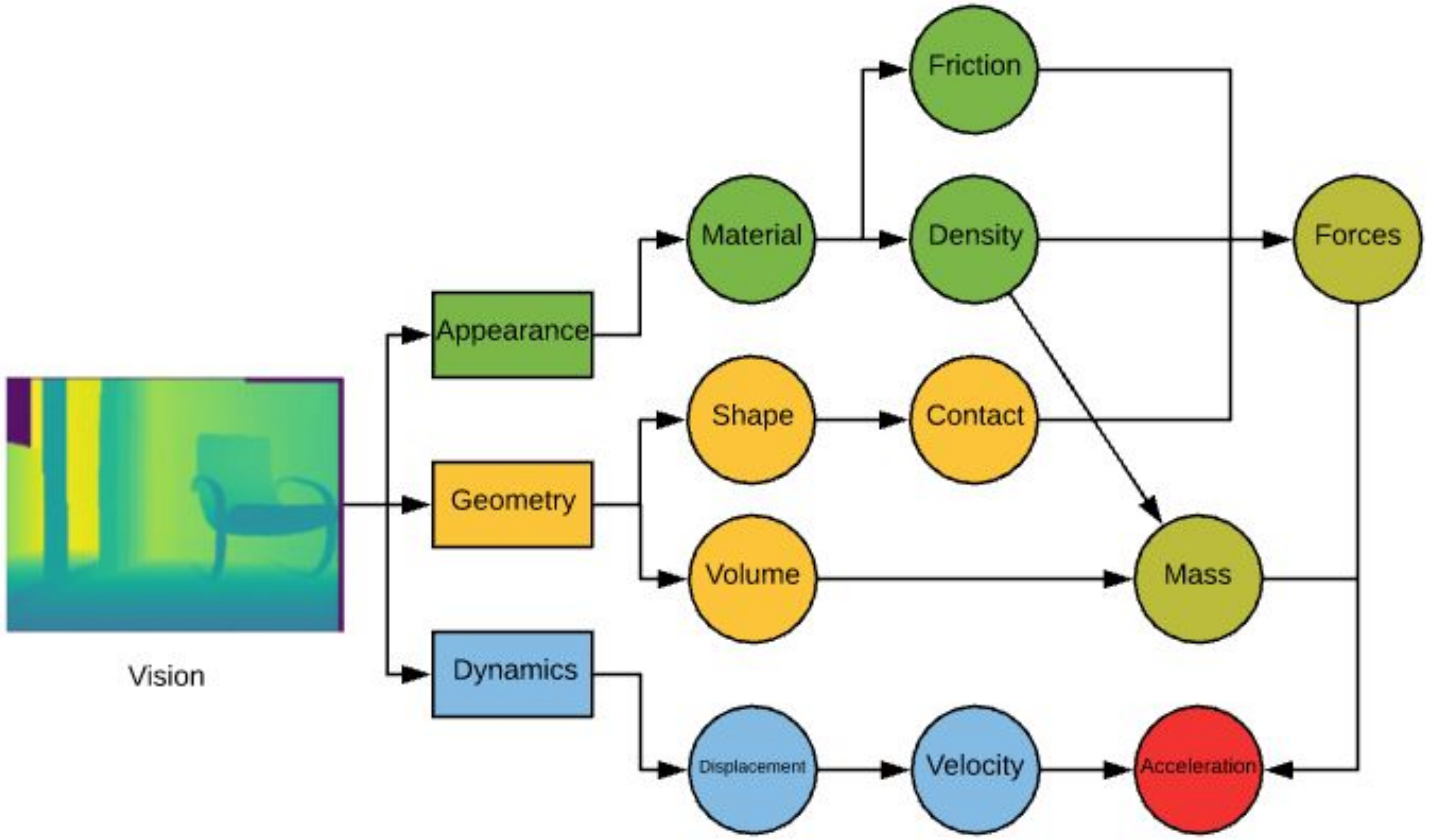


- Evaluation:
  - Correctness of estimation of chained DoF from demonstration
  - Accuracy of estimation of CoM and improvement with repeated demonstrations
  - Accuracy of estimation of material category



Physical Inference

- DoF extracted from invariants of relative movement matrices
- Static physical quantities estimated with priors, including CoM
- Physical quantities relations encoded in a Bayesian network
- CoM estimation improved by posterior update after observing physical events



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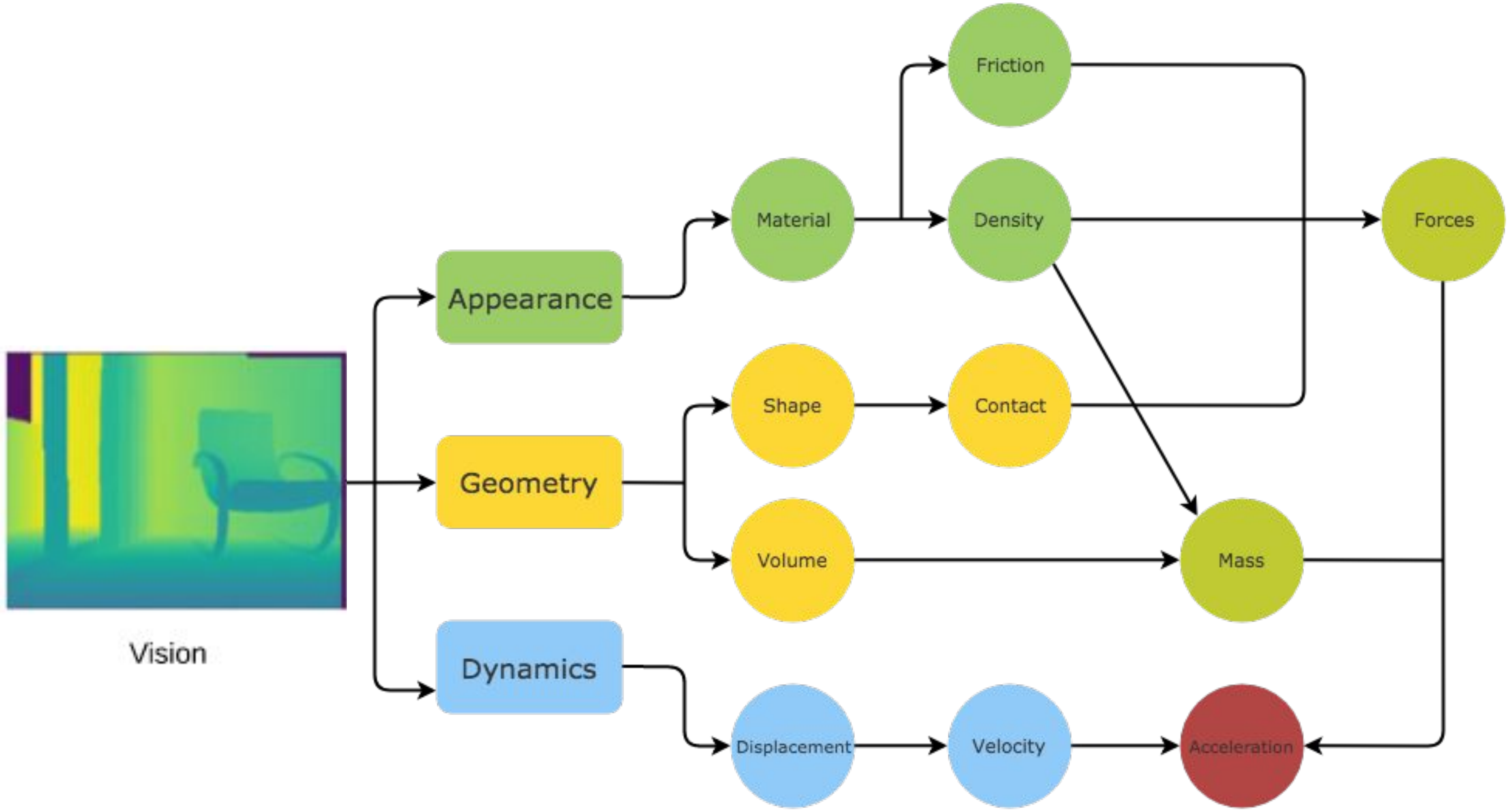
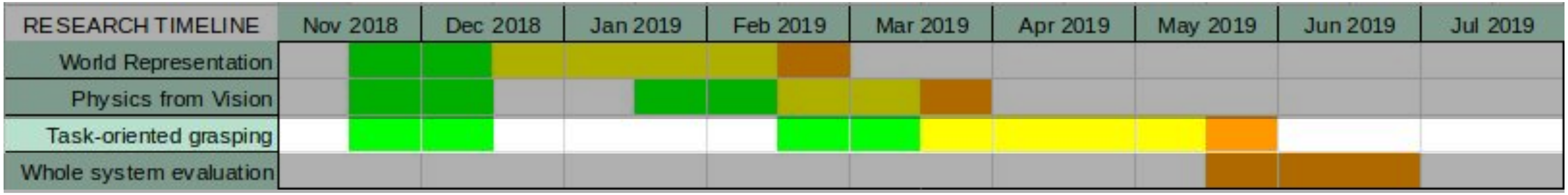


Task-oriented Grasp

- Objectives:
  - Define **limited** and **expressive** set of elementary physical tasks
    - Dexterity grasp
    - Lever grasp
    - Semantic grasp
  - Define strategy to plan grasps according to defined tasks
    - Bias grasp planning distribution according to task

- Evaluation:
  - Task correctness and robustness of execution of grasps
  - Test on simulation, validation on real robotic arm



Task-oriented Grasp

- Finite set of parametric grasp tasks:
  - dexterity grasp
  - lever grasp
  - semantic grasp

- Bias grasp planning distribution according to task

Future Works

- **Logic task planning:** chain tasks to achieve a high level objective

Antunes et al. From Human Instructions to Robot Actions: Formulation of Goals, Affordances and Probabilistic Planning, ICRA (2016)

- **Active perception:** plan physical interactions to explore the environment

Kim et al. Eye-in-hand stereo visual servoing of an assistive robot arm in unstructured environments, ICRA (2009)