istituto italiano di tecnologia

LCSL Laboratory for Computational and Statistical Learning

UNIVERSITÀ DEGLI STUDI DI GENOVA

Large-scale Incremental Machine Learning for Robotics

Img credits: C. Ciliberto

2nd Brains, Minds and Machines Summer School
2015/08/17

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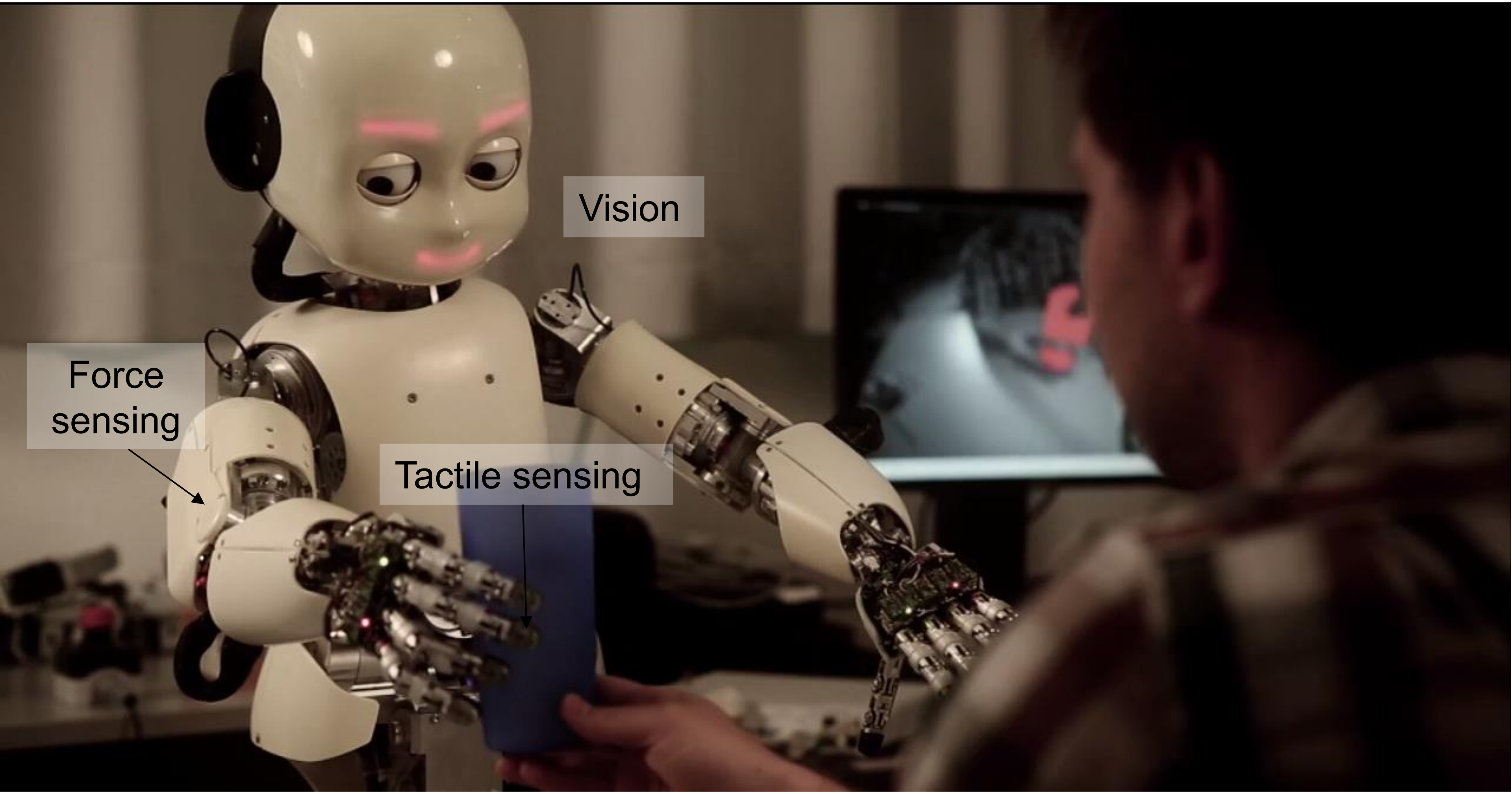
Advisors: Giorgio Metta, Lorenzo Rosasco

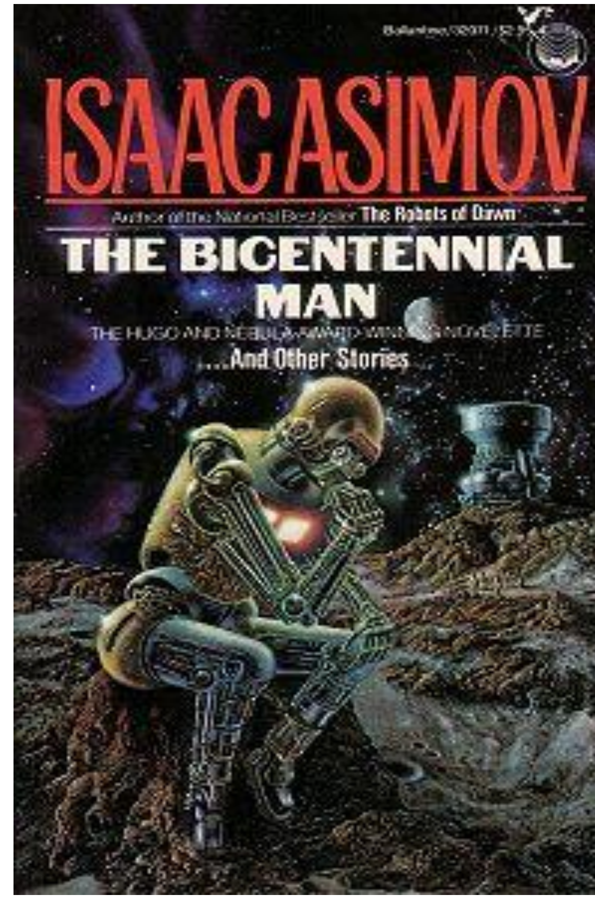
Modern robots are expected to operate in unstructured environments...

...and to learn new tasks on the fly...

...across different modalities...



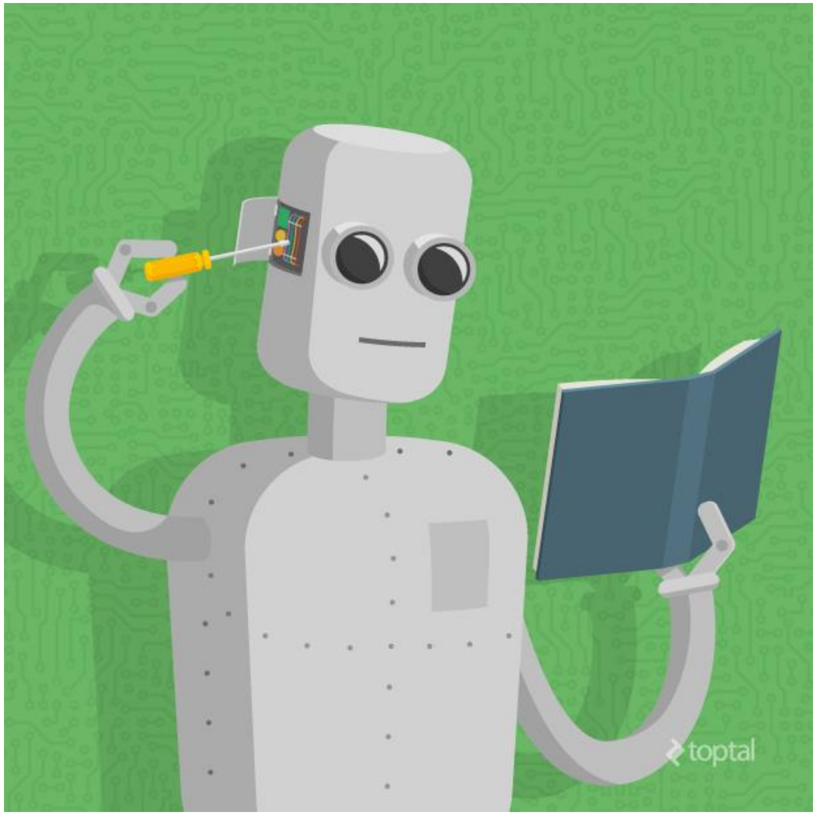
...throughout potentially very long time spans.



Machine Learning to the Rescue!

Machine Learning provides a number of useful tools for facing these challenges, e.g.:

- Large-scale learning methods
- Incremental Learning
- Transfer Learning



My Main Focuses

With

- Machine Learning
  - Large-scale Learning
  - Incremental Learning
  - Memory/time/accuracy tradeoff

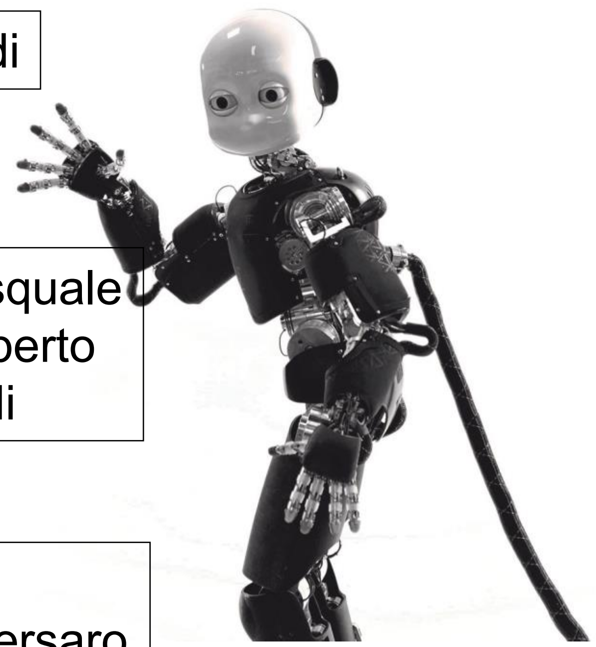
A. Rudi

- Robotics applications (on iCub)
  - Incremental object recognition

G. Pasquale
C. Ciliberto
A. Rudi

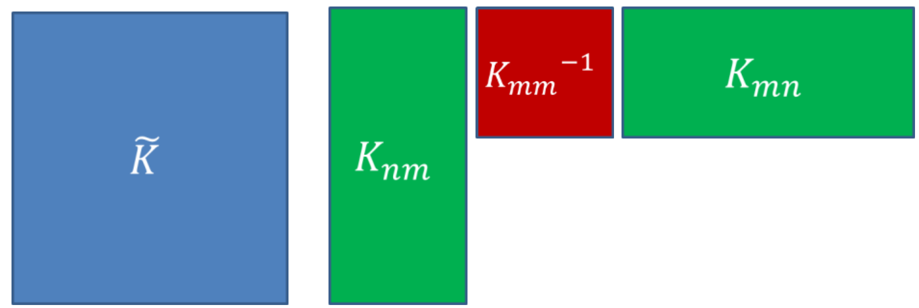
  - Dynamical system identification & estimation

F.Nori
S.Traversaro



Nyström Computational Regularization

- How to deal with a large number of examples *n*?
- Nyström method
  - Effective dimensionality < *n*
  - Approximate K drawing *m* << *n* points
    - Memory: $O(n^2) \rightarrow O(mn)$,
    - Time: $O(n^3) \rightarrow O(m^2 n + m^3)$
- A. Rudi, R. C., L. Rosasco, *"Less is More: Nyström Computational Regularization"*, NIPS 2015 (accepted) http://arxiv.org/abs/1507.04717
- **Nyström approximation as a regularization operation**



Time Complexity

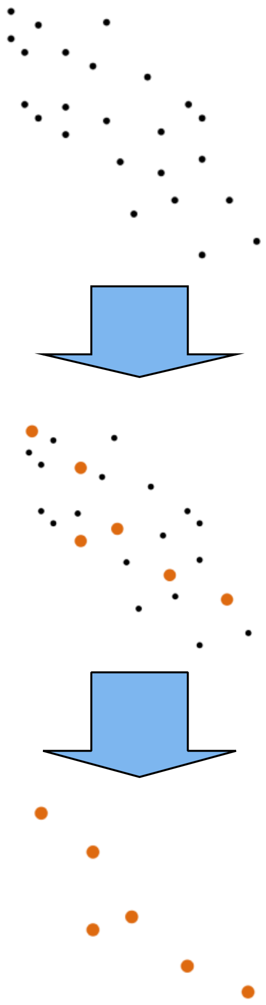
	Tikhonov KRLS
Exact formulation	$O(n^3)n_\lambda$
Incremental Nystrom formulation	$O(m_{stop}^2 n + m_{stop}^3 n_\lambda)$

Memory Complexity

	Tikhonov KRLS
Exact formulation	$O(n^2)$
Nystrom formulation	$O(mn)$

Nyström Computational Regularization

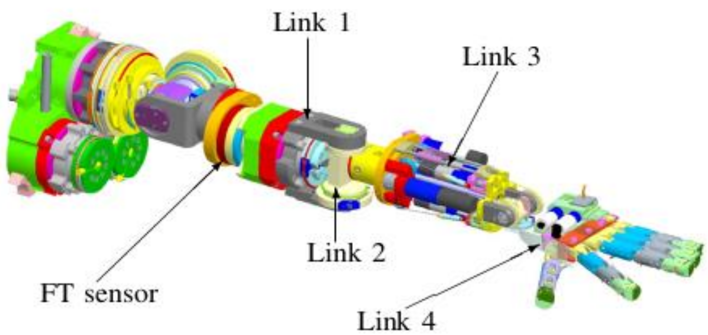
- Naive Nystrom KRLS: Compute a kernel approximation with a large *m* and then regularize with *λ*.
- Waste of resources (time & memory).
- Our variant of Nyström KRLS:
- Regularization can be viewed as "discarding" irrelevant eigencomponents
- *m:* trade-off parameter controlling both computational complexity **and** regularization



Incremental Object Recognition

- Scenario:
  - iCub detects an unknown object, which it cannot recognize with sufficient confidence
  - It shall be able to update its object recognition model adding a new class, without retraining from scratch (unsustainable in the lifelong learning setting)
  - This can be done, e.g. by means of a slight extension of RLS and proper reweighting
  - Open question: How to change the amount of regularization efficiently as n grows in time?

System Identification and Estimation

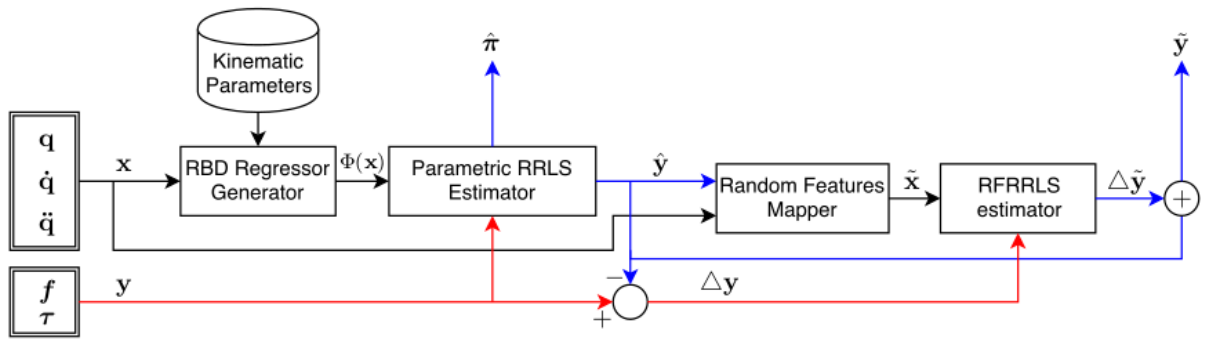


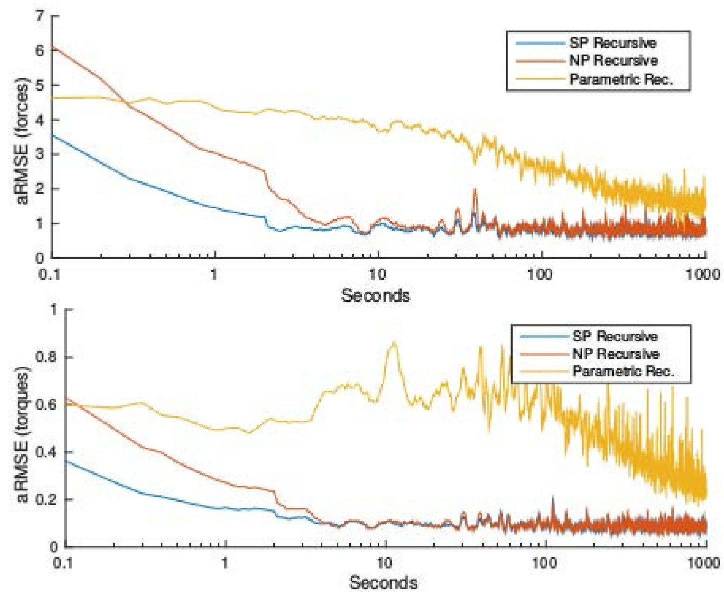
Source: Camoriano, Raffaello, Silvio Traversaro, Lorenzo Rosasco, Giorgio Metta, and Francesco Nori. "Incremental semiparametric inverse dynamics learning." In Robotics and Automation (ICRA), 2016 IEEE International Conference on, pp. 544-550. IEEE, 2016.

- Instance of incremental learning in the robotic motion domain
- Semiparametric inverse dynamics estimation and inertial parameters identification
- [f ; τ] = ID(q , dq/dt ,d^2q/dt^2) Multiple output regression problem
  - IN: q, dq/dt ,d^2q/dt^2 for the first 4 arm joints (shoulder + elbow)
  - OUT: Wrench (generalized force) measured by the F/T sensor placed in the arm

- Challenges:
  - Interpretability (join together physics-based parametric modeling and "black-box" nonparametrics)
  - Accuracy (beyond rigid body dynamics models, e.g. flexible bodies)
  - Adaptivity (the model adapts incrementally to change in system or environmental properties)

System Identification and Estimation





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The GURLS Library

- Grand Unified Regularized Least Squares
- Complete library for linear and kernel RLS
- Supports large-scale datasets
- MATLAB® and C++ APIs
- https://github.com/LCSL/GURLS
- Maintainers:
  - Alessandro Rudi
  - Matteo Santoro
  - Andrea Schiappacasse
  - Me

GURLS: a Least Squares Library for Supervised Learning.
Andrea Tacchetti, Pavan K Mallapragada, Matteo Santoro, Lorenzo Rosasco.
The Journal of Machine Learning Research. Volume 14, 3201-3205, 2013.

Resource: Brains, Minds and Machines Summer Course
Tomaso Poggio and Gabriel Kreiman