Applications of Reinforcement Learning in the Power Systems Industry

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with many thanks to
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RL & AI

Reinforcement Learning and Artificial Intelligence

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Reinforcement learning

- A new body of theory and algorithms for prediction and optimal control
- Developed in machine learning and operations research (also studied independently in psychology and neuroscience)
- Enables approximate solution of much larger problems than is possible with classical methods
- Also known as "neuro-dynamic programming" and "approximate dynamic programming

Reinforcement learning

- Learning a control law from interactions with the system or a model of the system
- Key technical ideas:
  - *Generality* of problem formulation
  - Learning from *sample system trajectories*

Generality of problem formulation

- Sequential decision-making
- Optimal control with general objective
- Arbitrary non-linear, stochastic dynamics
  - Markov decision processes (MDPs)
- Incomplete knowledge of dynamics
- MIMO

Learning from *sample system trajectories*

- Also known as "Monte Carlo methods" or "optimization from simulations"
- Approximation strategy with good scaling properties
- Dates to the 1950s and 1960s
- The new idea is to combine sampling with dynamic programming ideas — Markov state and the principle of optimality

RL has a very wide range of applications

- Helicopter auto-pilots
- Robots, RoboCup soccer
- Game-playing (chess, checkers, backgammon, RPGs, tetris, Go…)
- Dialog management
- Resource scheduling
- Inventory management
- Marketing
- Logistics
- Dynamic channel assignment
- Anomaly detection
- Visual search
- Queue management
- Real-time load balancing
- Power saving appliances
- ...

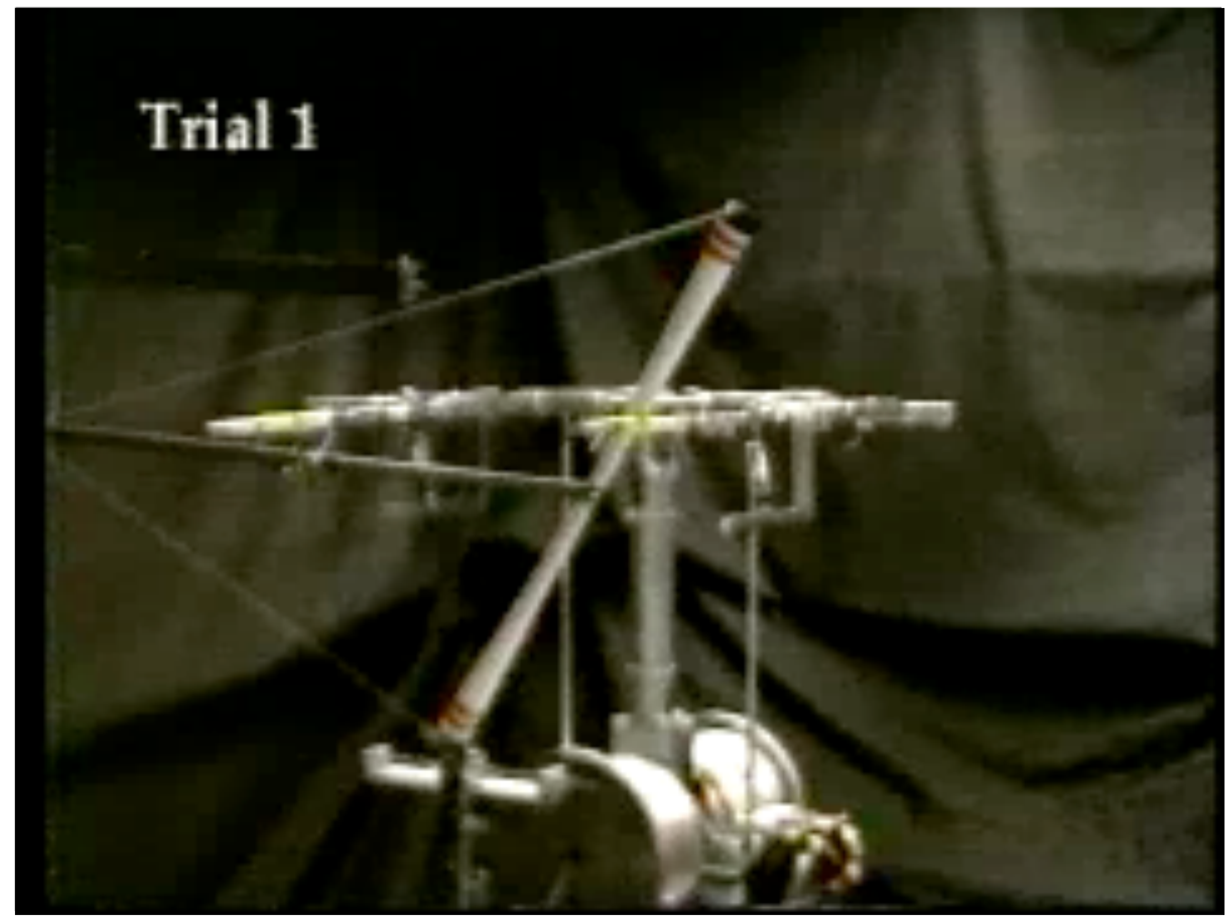
"Autonomous helicopter flight via Reinforcement Learning"

Ng (Stanford), Kim, Jordan, & Sastry (UC Berkeley) 2004


Stanford University Autonomous Helicopter

Devilsticking

Finnegan Southey
University of Alberta



Stefan Schaal & Chris Atkeson
Univ. of Southern California
"Model-based Reinforcement Learning of Devilsticking"

Applications in the Power Systems Industry

- The power systems industry faces a multitude of control problems
- These can be roughly categorized according to time scale
- 100s of research papers on applications of RL to power systems

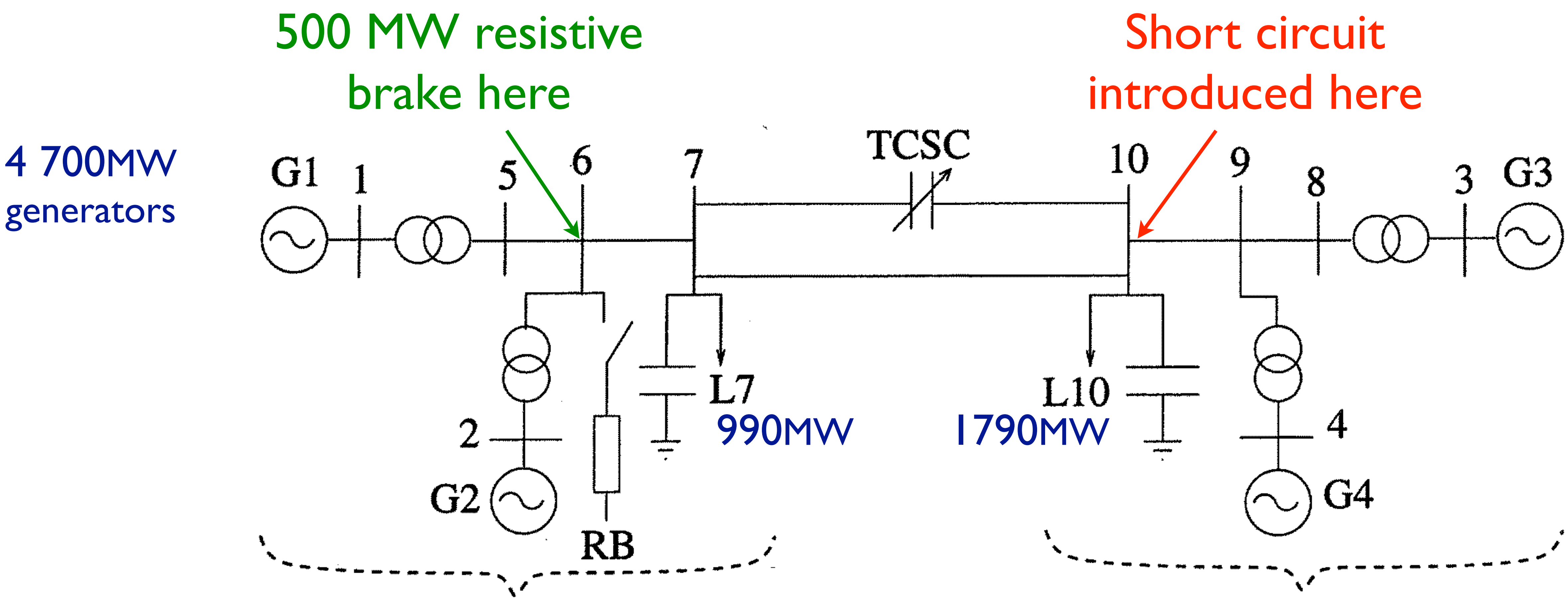
Case study in RL and PS

Offline design of a dynamic brake controller

Ernst, Glavic & Wehenkel, *IEEE Trans. on Power Systems*, 2004

Task domain

- Four-generator power system (simulated)



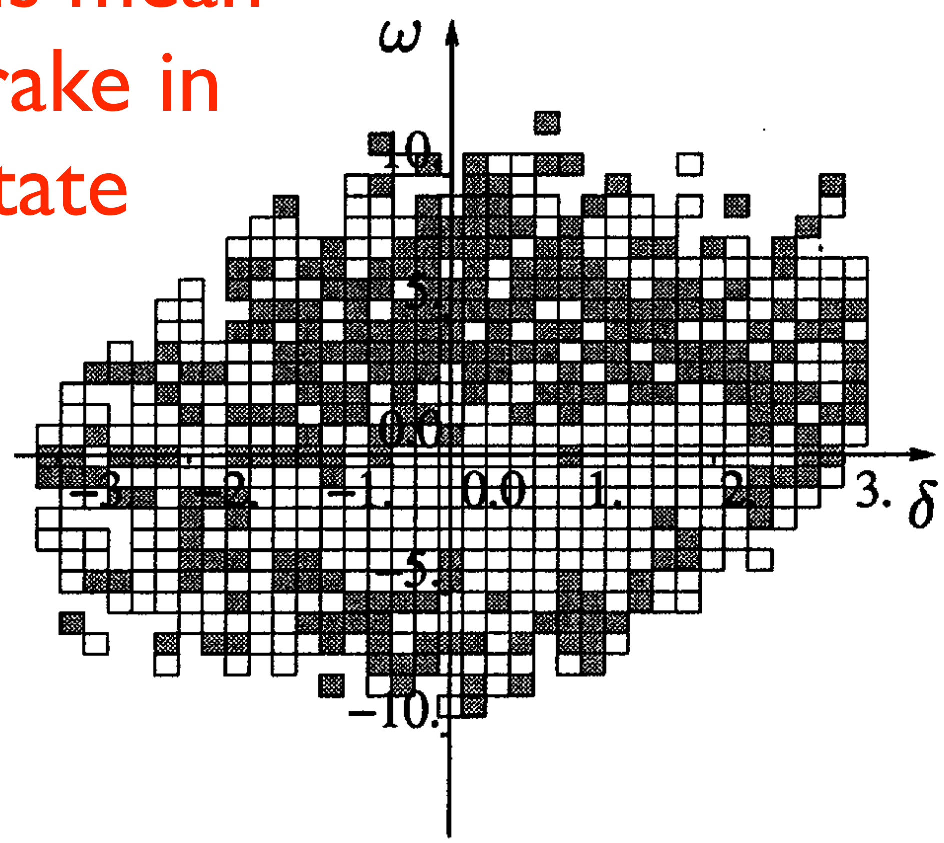
- Learn control law for applying brake

RL approach

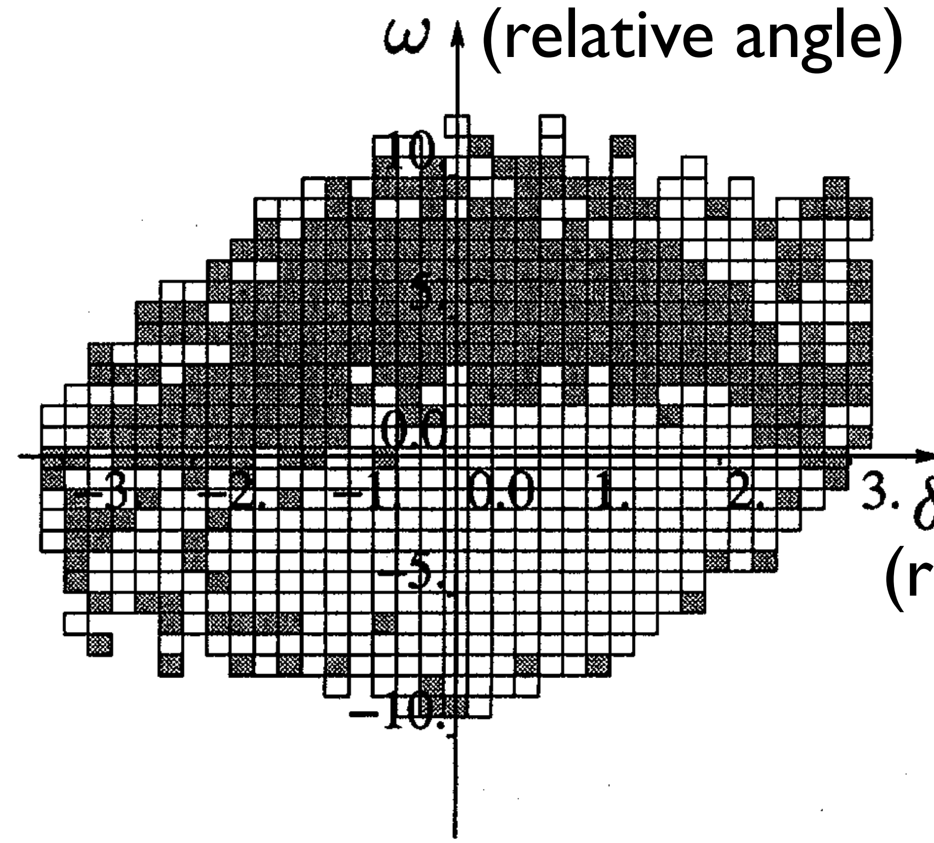
- State space reduced from 60 dimensions to 2 (relative angle and speed of the two groups of machines)
- Introduce penalties (negative rewards) for deviation of speed from zero, for applying the brake, and for loss of stability
- Learn discretized model of system
- Approximately solve system model for optimal value function and control law

RL results: Learned control law

Dark cells mean apply brake in the state



After 100 faults



(relative angle)

State space

(relative speed)

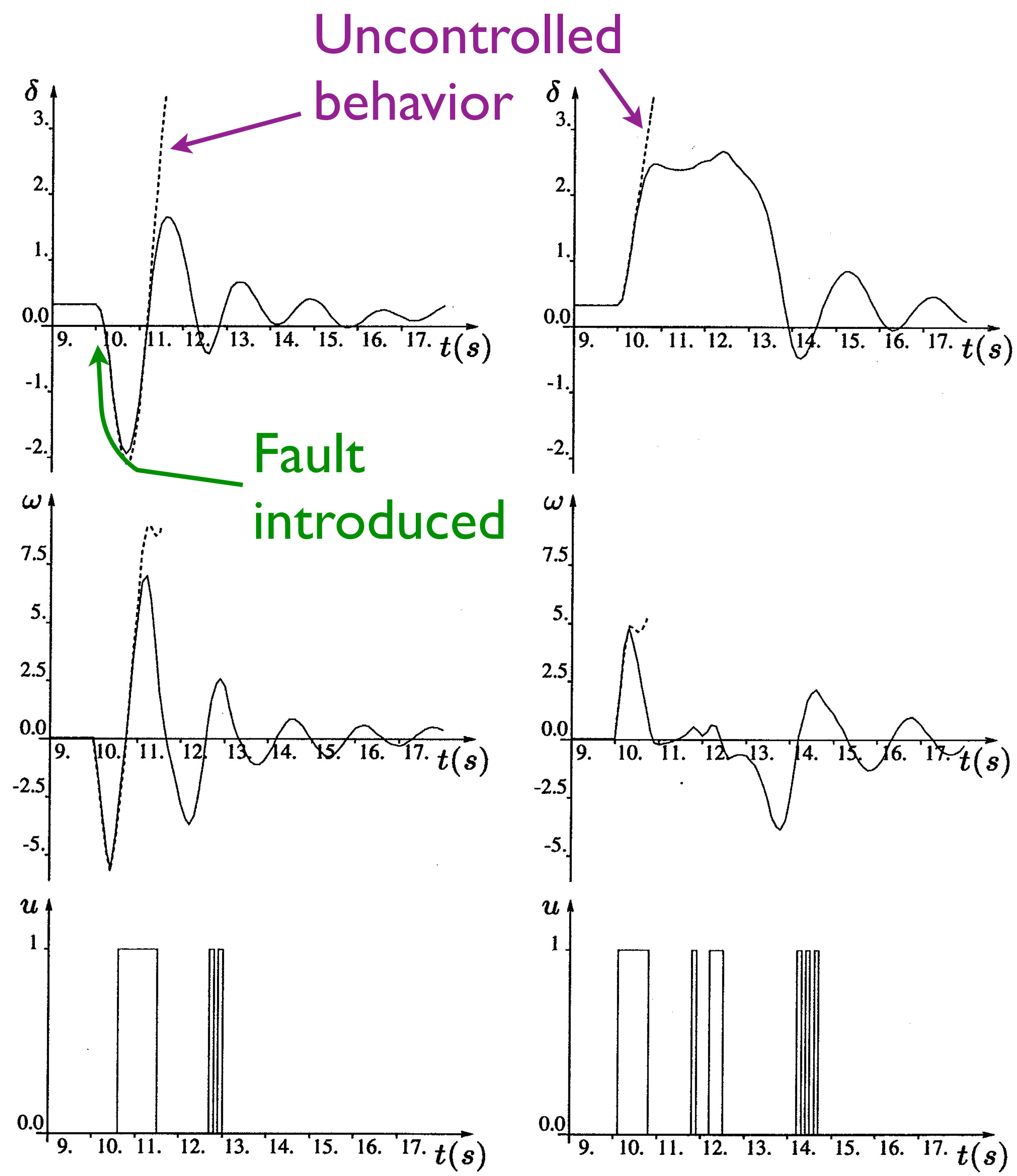
After 1000 faults

RL results: System behavior

Relative speed

Relative angle

Brake control



Trained fault
(bus 10)

Novel fault
(bus 7)

Good control, robustness

Conclusions from case study

- A specialized non-linear controller was created automatically
- Savings in engineering/design time
- Keys to application success:
  - Simplified state space
  - Domain is tolerant of small errors and imperfection in the controller
  - Domain involves sequential decision making

Apps of RL to Power Systems by time scale

- Tens of milliseconds (protection relays)
- Seconds (frequency and voltage control, damping)
- Minutes to hours (generation scheduling, load shedding, unit commitment, market bidding)
- Days to months (maintenance scheduling, longer-term generation scheduling)
- Years (investment, market rules)

Apps of RL to Power Systems by time scale

Currently most popular scales

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Overall conclusion

- The Power Systems Industry faces a multitude of control problems at time scales from milliseconds to years
- For many of these, RL methods are applicable and sensible
- The RLAI group here would be happy to provide some guidance in exploring possible applications and research projects