SYSTEM-OF-SYSTEMS THAT ACT **LOCALLY** FOR OPTIMIZING **GLOBALLY**

EU FP7 - SMALL/MEDIUM-SCALE FOCUSED RESEARCH PROJECT (STREP)
FP7-ICT-2013.3.4: ADVANCED COMPUTING, EMBEDDED AND CONTROL SYSTEMS
D) FROM ANALYZING TO CONTROLLING BEHAVIOUR OF SYSTEM OF SYSTEMS (SOS)

Local4Global KoM

Theoretical Tools

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Local4Global
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For information regarding this Project: Check the Project Web-Site: http://local4global-fp7.eu

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Overview of Presentation

- Existing Tools
- C4L/L2C (Control for Learning/Learning to Control)
- Self-Learning Mechanism
- Situation Awareness Mechanism
- Evolution/Emergent Behavior
- Advances required?

Existing Tools: The PCAO Algorithm (P-Cognitive Adaptive Optimization)

- Optimal Control: Optimize a performance index Π(State) over a time horizon
- State=sensor measurements for the 2 Use Cases
- Control=HVAC settings/Green times, vehicle speeds
- Π(State) = Consumption+Comfort/Mean Speed
- Solution: the Hamilton-Jacobi-Bellman (HJB) equation

$$\nabla V(\text{State}) \bullet (\text{Sys\_Dynamics} + B \bullet \text{Control}) = \Pi(\text{State})$$

- In general, non-solvable.
- Moreover
  - Needs full knowledge of Sys_Dynamics
  - Control=-B ● ∇V(State)
  - So, it suffices to find V(State)

Existing Tools: The PCAO Algorithm

- PCAO key idea:
- Approximate V(State) according to

$$V(\text{State}) \cong z(\text{State}) \bullet P \bullet z(\text{State})$$

  where P is **positive definite matrix** and z(State) is a piecewise linear vector
- Then, the problem is reduced to the problem of finding P.
- HJB

$$\nabla V(\text{State}) \bullet (\text{Sys\_Dynamics-B} \bullet \nabla V(\text{State})) = \Pi(\text{State})$$

- is equivalent to

$$V(t+1)-V(t)=\Pi(\text{State}) \bullet \text{Delta } t$$

- Define the Error

$$\text{Error}=(V(t+1)-V(t)-\Pi(\text{State}) \bullet \text{Delta } t)^2$$

- Thus, solving the HJB is equivalent to minimizing Error

Existing Tools: The PCAO Algorithm

- Error depends on system dynamics (thus standard optimization techniques are not-applicable)
- PCAO key idea:
  - Apply P and evaluate Error for the next time step
  - Construct an adaptive estimator for Error as a function of P
  - Generate many random candidate perturbations P+ΔP
  - Choose the one that optimizes Error.
- No need to know system dynamics!
- Must make sure that P+ΔP are positive definite.

PCAO and C4L/L2C

PCAO = C4L/L2C:

- Each time the control actions are “perturbed” so as to guarantee efficient learning
- Each time the control actions are “moving in the right direction” as they minimize Error (or equivalently the HJB discrepancy)
- But ….

C4L/L2C & the Self-Learning Mechanism

Can we extend PCAO to System-of-Systems?

- HJB for SoS
- Adaptive Estimators for SoS
- "Just enough learning"

Stochastics, continuous and discrete dynamics, automata and other ingredients from computer science theory, ….

The Situation Awareness Mechanism

What happens if only local measurements are available?

- Need to C4L/L2C not only to learn but also to “understand what is happening”
- Just-enough-estimating
- Observers?
- Extend of HJB concepts by augmenting the cost function?

$$\Pi(\text{State})+\text{Observation\_Accuracy}$$

- Take ideas from sensor networks and robotics (e.g., Observation_Accuracy=trace of EKF covariance error matrix)?

Evolution/Emergent Behavior

Operate locally so as to follow a global behavior

Control of such a global behavior (only using local actions)

Is defining a “proper” objective function enough?