

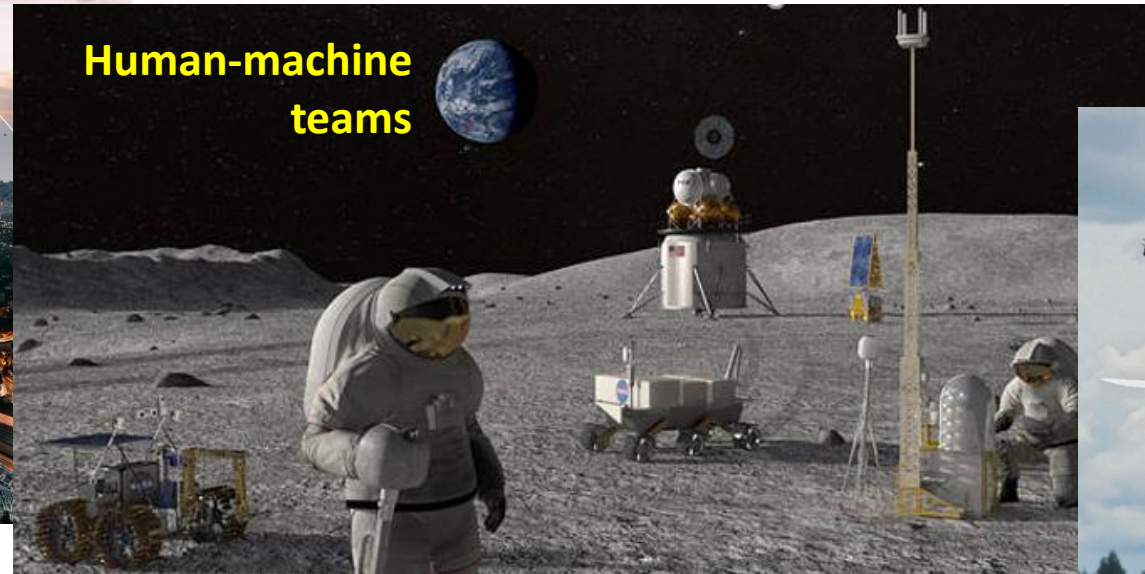


MAGE: Alleviating Uncertainty in Real-Time Decision-Making as a Function of Problem Complexity

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AIAA SciTech, January 2022

Problem Setting



A critical aspect of uncertainty in the operation of complex systems: the ability of agents to arrive at satisfactory decisions and the attendant actions in time, as a function of problem complexity

Image credits: NASA

Complexity



- Reducing uncertainty to achieve manageable operation is always done via bounding problem complexity
- Current airspace control:
 - Static complexity bounds
 - Related to cognitive capacity of human controller
- Goal: Bound complexity in a dynamic and scalable way amenable to computational decision-making in human-machine and autonomous machine systems
- Want:
 - Keep the system sufficiently simple
 - Represent complexity in computable, actionable form
 - Detect approaches to unacceptable complexity
 - Reconfigure system to forestall transition to unacceptable complexity
 - Reconfigure system once increased complexity is resolved

Proposed Measure of Complexity



- Tractability, with a look ahead, of the solution problem on a time budget, as a function of the external and internal parameters. For air traffic:
 - External parameters, e.g.: density and heterogeneity of the relevant airspace volume
 - Internal parameters, e.g.: physical properties of the aircraft and computational properties of decision-making algorithms
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- The quality of solutions of the decision-making problem measured in terms of constraint satisfaction, optimality, and robustness. For air traffic:
 - One measure of robustness: robust solutions live in the regions of space that allow for many alternative solutions (e.g., flexibility preservation, Idris et al.).

Conceptual Approach



Given:

An agent and a goal

Initialize:

Set time $t=0$

Set initial sampling time interval Δt

Set initial look-ahead time T

Set initial look-ahead sampling time interval $\Delta \tau$

Select initial problem-solving algorithm P

Select environmental complexity parameters C

Select initial environmental complexity model M

Select transition criteria

Select stopping criteria

Conceptual Approach, cont.



Do until (stopping criteria are satisfied)

Acquire and assess complexity parameters C at time t

Set $\tau = t$

Do while ($\tau \leq t + T$)

Estimate look-ahead complexity parameters at time τ

$\tau = \tau + \Delta\tau$

End do

Input complexity parameter array to complexity model M ; assess approach to phase transition

If (approach to transition detected) then

Update Δt , $\Delta\tau$, T

Reconfigure operations toward goal

Else

Assess system's performance slack

If (slack)

Reconfigure operations toward goal

Else

Continue present operations toward goal

End if

End if

$t = t + \Delta t$

End do

MAGE (Monitor, Anticipate, Guide, Evolve) for Air Traffic



- Complexity model construction:



- Reconfiguration: change in the decision problem objectives, constraints, and variables

- Directed modification
- Autonomous, distributed modification with emergent outcomes
- Hybrid directed-autonomous
- Example: reduce weight of the delay objective in high-risk, dense environment

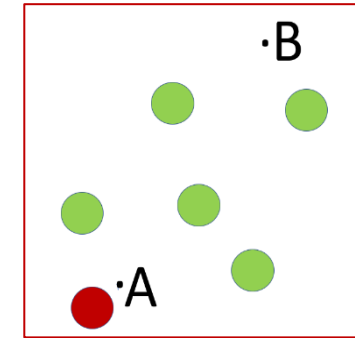
- Decision-making strategies:

- Solution strategy (e.g., optimization) affects the outcome of actionable complexity prediction.
- As new capabilities arise, complexity models must be re-calibrated

Initial Numerical Tests of Tractability Prediction

- Shortest Path Finding via Visibility Graph

# obstacles	# scenarios	Avg. # solutions	Avg. time to solution (sec)	# test scenarios	Avg. # test solutions	Avg. % time prediction Δ
4	100	97	0.86	25	24	0.02
5	100	89	1.31	25	19	0.07
10	100	34	324.33	25	7	2.03
20	100	2	4800.00	25	Not found	N/A



- Minimization of Deviation from Optimal Path

# obstacles	# scenarios	Avg. # solutions	Avg. time to solution (sec)	# test scenarios	Avg. # test solutions	Avg. % time prediction Δ
4	100	94	0.38	25	25	0.01
5	100	100	0.37	25	23	0.01
10	100	83	11.60	25	24	0.03
20	100	86	64.52	25	19	0.05

- Detect trends in computational tractability of simple decision problem formulations, using examples of two formulations and two decision-making schemes.
- Results to date indicate that further development of the planned complexity models is justified.

Concluding Remarks



- The proposed approach is aimed at reducing system uncertainty by “conditioning” the system to be sufficiently simple to allow each agent to solve its decision-making problem.
- We are cautiously optimistic about the predictive capability of the approach because, in the case of air traffic, few comprehensive problem formulations will be used.
- DOE of more realistic scenarios is in development for data collection and complexity model construction.

Acknowledgments

The author thanks the NASA Langley Research Center CIF/IRAD Program for supporting this work.