RESILIENCE IN ROBOTIC COLLECTIVES

Jennifer Leaf, Advisor: Dr. Julie A. Adams

PROBLEM STATEMENT

Resilience is the ability to “bounce back” from unexpected events, adjust to current circumstances, and persist in an unfamiliar or even hostile environment. Robotic systems are composed of autonomous agents, which are computational systems that execute algorithms and are embodied in a hardware platform. Agents execute algorithms in order to accomplish one or more assigned goals.

Existing definitions of resilience describe how well systems are able to recover performance after an unexpected disturbance and return to a previous operating state. Alternative definitions are required when reaching the goal state is the primary system objective.

DEFINING RESILIENCE

Autonomous agents must demonstrate a sufficient level of competence to perform a task that achieves a goal. Resilience in autonomous agents is considered to be an extended form of competency.

A resilient agent can still observe enough of the world, have enough control authority, and have an algorithm that continues to compute solutions that satisfy a goal predicate, given available computational resources, even when the agent or environment is disturbed.

MEASURING RESILIENCE

Robotic systems that execute algorithms in order to accomplish a goal may not exhibit stability in system variables, nor continuity in its behavior, in order to satisfy the goal conditions. When a metric for a collective changes from the baseline, it may indicate progress towards task completion; thus, it is undesirable for the collective to return to the previous baseline state.

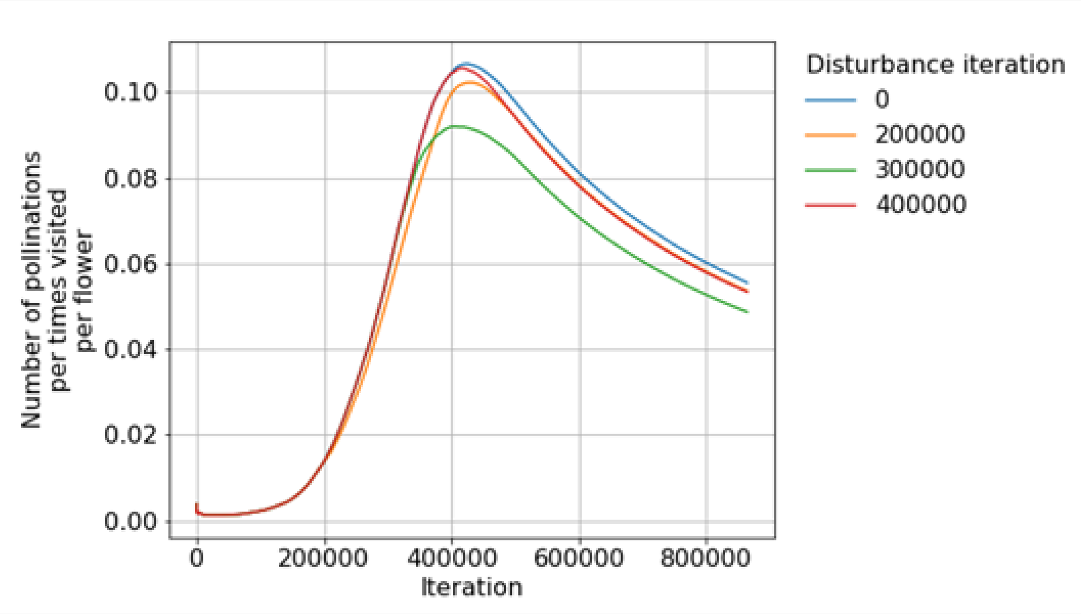

Figure 1: Agents pollinating a field of flowers strive to find and pollinate as many flowers as possible, given current operating conditions. The flowers’ bloom cycle means that a stable performance metric for pollination is not applicable to determining whether the agents are accomplishing their task. The timing of a disturbance to the field affects the agents’ efficiency.

A more relevant metric for assessing the resilience of computational systems is based on two factors: a) the probability of the algorithm to reach a goal state b) before a deadline.

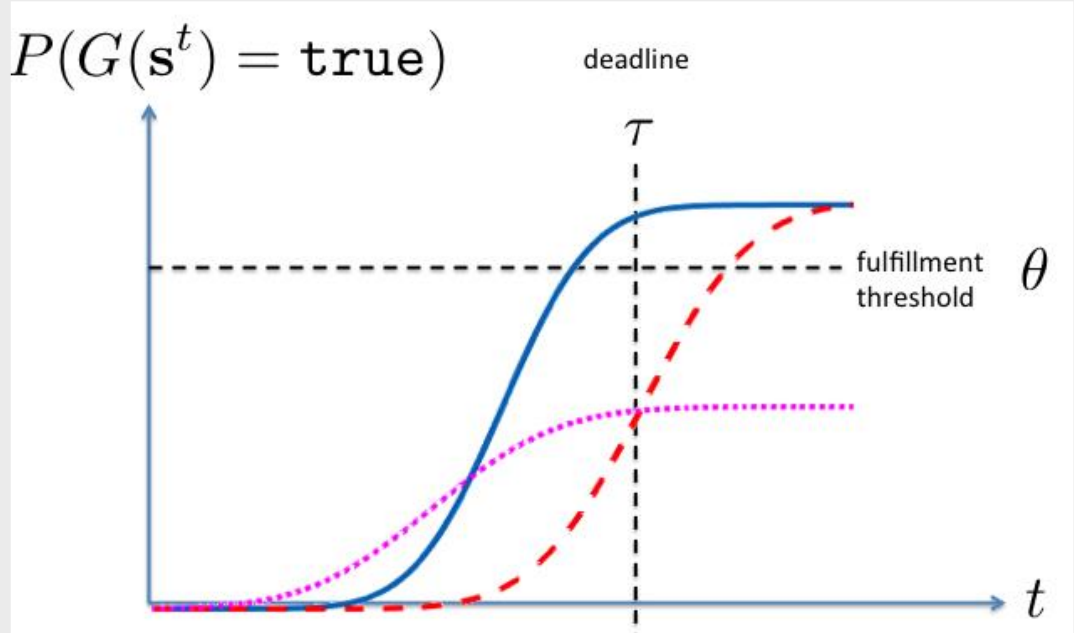

Figure 2: Autonomous computational agents must achieve both the fulfillment threshold θ and the deadline τ in order to satisfy their goals (blue line). Agents that are unlikely to accomplish the goal state (purple dotted line) or reach the goal too slowly (red dashed line) after an unexpected event are not considered to be resilient.

DESIGNING RESILIENCE

Design patterns for resilient systems are a valuable tool to complement analytical techniques in system design and validation. Four major categories of resilience principles exist:

- Capacity: how the system can continue to operate after a disturbance occurs.
- Flexibility: how the system can adapt and change in response to a disturbance.
- Tolerance: how a system can gracefully degrade without complete failure.
- Cohesion: how components within a system collaborate and coordinate actions in order to act as a unified whole to restore the system.

TESTING RESILIENCE

The Indoor Collective Robotics Testbed at Oregon State University is being developed to validate collective robotics systems research on actual hardware. Robotic collectives offer the potential to perform spatially distributed, complex tasks using robotic platforms with individually simple behaviors. The testbed reflects the imperfections of real-world operating conditions, which is critical for evaluating resilience.

Figure 3: The Indoor Collective Robotics Testbed with 70 aerial and ground vehicles simultaneously exploring the platform.

CONTRIBUTIONS

A goal-centric definition of resilience, along with relevant metrics for measuring resilience, will allow autonomous agent researchers to quantify how algorithms and robotic systems operate in dynamic and unpredictable environments, furthering the development of robotic systems that can operate well in real-world conditions.

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