Request for Information (RFI)
DARPA-SN-15-51
Design of Dynamically Composed Systems of Systems

Responses Due: June 11, 2015 by 4:00 PM (Eastern)
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URL: http://www.darpa.mil/Opportunities/Solicitations/DSO_Solicitations.aspx

The Defense Advanced Research Projects Agency (DARPA) Defense Sciences Office (DSO) is requesting information concerning research related to analysis and design frameworks for dynamically composed networked system of systems (SoS) architectures.

SoS architectures of interest to DARPA/DSO use networked teams of manned and lower-cost unmanned systems to accomplish mission objectives. While this teaming approach may lower costs, reduce development time, and improve mission effectiveness, there is no unified analysis framework that provides a quantitative assessment of the performance trade space including campaign/mission effectiveness across mission environments, detailed system physics, and cost/sustainment.

DARPA/DSO is interested in computational frameworks and methodologies to enable this unified analysis and design infrastructure for SoS architectures. Of particular interest are frameworks and methodologies from outside the traditional aerospace, systems engineering, control theory, and computer science domains that pertain to the understanding and design of complex interactions of systems of independent entities with coordinated responses across multiple time and length scales. For example, there may be relevant research findings or modeling approaches from the coupling of molecular-level systems biology to physiology or population ecology in biome modeling, quantitative analysis of human team performance, psychology and teaming strategies in collaborative activities, and resilience analysis of coupled financial networks that could inform SoS design.

Additionally, the SoS framework enables the dynamic composition of “services” provided by the constituent systems to achieve desired coordinated responses, or “applications,” in response to changing operational conditions subject to resource constraints. Modeling and designing both the SoS that embodies this dynamic, multi-scale behavior and the architecture of underlying composable systems requires an entirely different design and analysis framework than the traditional federated, hierarchical modeling approaches currently employed.

The difficulty of modeling a dynamic, composable SoS is compounded by the teaming of humans with large numbers of low-cost autonomous vehicles that have fundamentally different interaction and decision dynamics than other humans. The best modes for human interaction with large numbers of autonomous systems to accomplish dynamic mission goals, in addition to how to efficiently model the autonomous system behaviors, require definition for the larger SoS design framework.

DARPA/DSO is interested in information related to new modeling, analysis and design methods to address these SoS design challenges. DSO anticipates these methods could achieve transformative improvements in the ability to model and design SoS architectures with unprecedented dynamic properties. Although this RFI primarily seeks information regarding modeling and simulation, other novel methodologies that enable the desired transformative analysis and design capability are also of interest.

This RFI is requesting responses in four interrelated Technical Areas (TAs):

- TA1: Data management and manipulation for networked, multi-scale SoS;
- TA2: Design tools for constrained, coordinated composability;
- TA3: Design of man-machine teams for a dynamically composed SoS; and,
- TA4: Design and evaluation of "living" system-of-systems architectures.

Responses need not be exclusively focused on a specific TA, nor be over-constrained by uncertainty over which TA a technology fits. Responses that build upon speculative knowledge should explicitly state assumptions and presumed technological developments.

TA1- Data management and manipulation for networked, multi-scale SoS: DSO is interested in computational and mathematical frameworks that fundamentally remove the difficulties associated with managing dynamic interactions between systems networked across multiple length and time scales. For example, category theory may provide a framework to systematically compose and integrate systems that span multiple time and length scales. Alternatively, computational algorithms for dynamic service composition, planning or scheduling may provide a basis for a broader framework relevant to the SoS design problem. Respondents should explicitly address how their mathematical or computational framework addresses the fundamentally multi-scale and heterogeneous networked nature of the SoS problem with an example that shows practical application. Computational "wrappers" or approaches that extend existing systems engineering tools such as Systems Modeling Language (SysML) are explicitly not of interest.

TA2 - Design tools for constrained, coordinated composability: DSO is interested in computational frameworks that allow analysis and design of dynamically networked composable SoS architectures. Of particular interest are frameworks that enable design and quantitative assessment of coordinated multi-scale phenomena with cost constraints, especially the "inverse problem" of composing an application from distributed, multi-agent, and mobile constituent services. In the military application, an example scenario would be coordinated EW, ISR and strike, with dynamic reconfiguration across mission spaces in response to a changing operational environment with explicit accounting for logistics. Analogous problems exist in systems biology and in urban planning; modeling and design frameworks from these fields that provide insights into the design of coordinated behaviors as a function of cost metrics and enable inverse analysis are of interest. Since interactions between constituent systems and subsystems across multiple time and length scales are a defining characteristic of SoS architectures, respondents should discuss how these interactions are modeled using appropriately detailed physical models and/or data assimilation techniques with accounting for uncertainty. Of particular interest are frameworks for analysis of and design for resilient response to "stress test" cases such as loss of communications, unanticipated interactions between constituent subsystems and/or systems, and attacks on the SoS, including attack by an adversary SoS. Approaches using traditional federated hierarchical modeling frameworks are explicitly not of interest.

TA3 - Design of man-machine teams for a dynamically composed SoS: DSO is interested in approaches to model and design dynamic SoS architectures employing mixed teams of human and autonomous assets such that collective intelligence and function are dynamically optimized. Of particular interest are tools to assess and design the distribution of functions across heterogeneous autonomous systems collaborating with humans to achieve dynamic and coordinated “application” effects for subsequent inclusion in the overall SoS design tool. Respondents should address how “services” provided by a heterogeneous collection of multiple human and autonomous systems can be dynamically and optimally recomposed in response to changing environmental conditions with design guidance for what roles the humans and autonomous systems should serve. Respondents should also address how the autonomous systems will interact with or infer intent of the humans in the composed SoS. A possible approach is to organize human and autonomous agents into “societies” that function across varying trust domains, activity enclaves and network/perception hierarchies, with machine systems extending human expertise or optimizing human attention in a dynamic environment. The “meta” exercise of how to use teams of humans and machines to design man-machine teams for maximum effectiveness is of interest for this TA; for example, using humans to represent autonomous systems in models and then extracting agent rules from the data is one such approach. Modeling techniques that are computationally more efficient than traditional agent based models for many agent complex interaction dynamics are also of interest. For example, methods based on quantitative analysis of human teams engaged in continuously variable activities such as music performance or dynamic sports like basketball, hockey or soccer may provide insights into appropriate team dynamics and communication more readily than agent-based modeling approaches.

TA4 - Design and evaluation of “living” system-of-systems architectures: DSO is interested in approaches to build in dynamic, “living” response to changing conditions. Current SoS concepts are largely static teams of systems with coordinated defined functions. By making the SoS dynamically reconfigurable, it may be possible to realize systems with disruptive fluidity, resilience and adaptability (a “superorganism”). The challenges in achieving this robust “living” response span both the SoS and constituent system architectures: Is the dynamism realized at the SoS level, the system level, or both? Is the fluidity accomplished using multiple low cost systems or systems with reconfigurable, composable properties? If the latter, how is this composability achieved and is it cost effective? Modeling approaches of interest could include heterogeneous networked systems controls theory, non-Markovian planning and scheduling, complex systems models drawing on improved understanding of agent-agent dynamics, or concepts from biology that draw on functional degeneracy and ecological understanding to enable unprecedented performance. Respondents should illustrate how their methods are able to assess multi-scale functional capabilities in the resulting adaptive structures within the SoS and provide metrics for the improvement over state-of-art approaches. As an example, realization of emergent structures in a swarm of robots via local communication or interaction rules is insufficient. The swarm should be heterogeneous and possess multiple functional behaviors (e.g., motion, lifting and sensing) such that the adaptive response provides a higher level aggregate function (e.g., collective detection of a moving large obstacle, reconfiguration and transport of the object around the obstacle) and is resilient to loss of constituent systems, communications, and a dynamic operating environment.

In addition to the four technical areas described above, respondents may also suggest ideas they believe are under-investigated and under-invested but could enable the desired transformative design capability. Speculative concepts with insight into practical application are encouraged, especially where they represent a potential revolutionary advance over current capabilities.

SUBMISSION FORMAT

Multiple TAs may be addressed in the same response, with a clear statement of which TAs are being addressed in the first sentence. Respondents to this RFI are encouraged to be as succinct as possible, while also providing actionable insight. Responses are limited to 6 total pages (cover page + 5 page technical description), plus an additional page for each additional TA addressed. For example, a response that addresses TAs 1, 2, and 4 may include 1+5+2 = 8 total pages.

Format specifications for responses include 12-point font, single-spaced, single-sided, 8.5 by 11 inches paper, with 1-inch margins in either Microsoft Word or Adobe PDF format. Each submission must include a cover page which provides the following information:

a. Title
b. Technical Area
c. Organization
d. Technical point of contact name, telephone number, and email address

SUBMISSION INSTRUCTIONS AND CONTACT INFORMATION

All responses to this RFI must be emailed to DARPA-SN-15-51@darpa.mil. Please refer to the "DARPA-SN-15-51 RFI" in all correspondence. All technical and administrative correspondence and questions regarding this announcement should also be submitted to the same email address. Emails sent directly to the Program Manager may result in delayed/no response.

DISCLAIMERS AND IMPORTANT NOTES

This is an RFI issued solely for information and new program planning purposes; it does not constitute a formal solicitation for proposals. In accordance with FAR 15.201(e), responses to this notice are not offers and cannot be accepted by the Government to form a binding contract. Submission is voluntary and is not required to propose to a subsequent Broad Agency Announcement (BAA) (if any) or other research solicitation (if any) on this topic. DARPA will NOT provide reimbursement for costs incurred in responding to this RFI. Respondents are advised that DARPA is under no obligation to acknowledge receipt of the information received or provide feedback to respondents with respect to any information submitted under this RFI.

NO CLASSIFIED INFORMATION SHOULD BE INCLUDED IN THE RFI RESPONSE. Respondents are responsible for clearly identifying proprietary information. Responses containing proprietary information must have each page containing such information clearly marked with a label such as "Proprietary" or "Company Proprietary." DARPA will disclose submission contents only for the purpose of review.