Software-Defined Governance: Applying Computational Norms

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Gap analysis and challenge. Advances in software-defined infrastructure and exchanges open up the possibility of flexible resource allocation geared to supporting dynamically changing user needs. Major trends such as the Internet of Things and large-scale analytics speak to the importance of effective collaboration among a variety of stakeholders, including users and operators. Such emerging use cases demand adaptive and scalable *governance*, understood as collaborative administration of shared resources.

However, current approaches for governance are limited. Governance is tackled through a combination of rigid policies applied computationally and ad hoc responses applied manually ("governance by phone call"). Existing approaches, therefore, both interfere with the autonomy of stakeholders and preclude the level of flexibility in resource allocation that is necessary in modern application scenarios. The challenge I address is how to facilitate flexible governance in emerging network infrastructures.

Vision: Governance via norms. I initiated the research direction I describe here as part of the NSF's Ocean Observatories Initiative (OOI). The OOI brought together a wide variety of resources at the network level and up that were geared to supporting scientists and institutions sharing resources, including data-streams from (mobile or stationary) ocean sensors. The OOI was intended to last for decades. Emerging software-defined infrastructure highlights the same characteristics: multiple autonomous stakeholders; potentially complex and conflicting requirements; heterogeneous resources; need for proactivity; and longevity, indicating we need a standard of correctness independent of specific technical artifacts.

I understand these systems as *sociotechnical systems (STSs)*, which include autonomous principals interacting with each other about and through ICT resources. Unlike traditional approaches, I wish to incorporate the social considerations in the design space. I model STSs through a recursive formulation of *Orgs*, specified according to *normative relationships* among stakeholders—or *norms* for short. These norms specify the rules of encounter of the given STS: they yield a standard for correctness that is independent of implementation. Norms are inspectable and can be reasoned about as formal objects.

With coworkers, I have developed formal semantics for norms—a basis for determining whether an enactment satisfies or violates a norm. The semantics helps identify and tackle conflicting stakeholder requirements and verify if an STS would preserve useful properties, such as liveness. We have developed a query language for computing norms state based on observed events as well as a way to exchange information across a decentralized system to ensure that interacting parties maintain a consistent view of the norm state. This work has appeared in leading AI, multiagent systems (MAS), and service computing venues.

I envision *software-defined governance* as an approach in which stakeholders' requirements are expressed as norms and automatic reasoning about these norms helps tackle governance in an efficient and effective manner. To realize this vision will require research on vocabularies for expressing governance requirements formally regarding networking; concomitant decision procedures for automated reasoning about norms expressed in those vocabularies; bases to validate policies and architectures with respect to norms; means to explore governance tradeoffs in terms of functionality supported and timeliness and quality of decision making; empirical studies to validate representations with respect to stakeholder needs.

Value proposition. Software-defined infrastructure needs flexible, efficient governance. Computational norms developed in AI and MAS can provide the necessary foundation via interdisciplinary research.

Bio. Munindar P. Singh is a professor in the Department of Computer Science at North Carolina State University, where his advisees have earned 20 PhD and 27 MS degrees. Munindar has authored several papers and a book *Service-Oriented Computing*. His research has been recognized with awards and sponsorship by (alphabetically) Army Research Lab, Army Research Office, Cisco Systems, Consortium for Ocean Leadership, DARPA, Ericsson, IBM, Intel, National Science Foundation, National Security Agency, and Xerox. Munindar is the editor-in-chief of *ACM Transactions on Internet Technology*; previously, he was the editor-in-chief of *IEEE Internet Computing*. He has served as associate editor for several journals. Munindar is a Fellow of the IEEE and received the 2015 NCSU Outstanding Research Achievement Award.

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