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Framework for Characterizing Complex Systems under Test

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In this white paper we document a framework for characterizing the boundaries of a complex system under test. In the context of PATFrame (Prescriptive and Adaptive Test Framework) [1], a complex system under test can consist of an autonomous and/or a network-centric system or system of system. Autonomous systems have been characterized using autonomy levels ranging from tele-operation by human operators to fully intelligent systems capable of autonomous planning, control and adaptive behavior [2]. Network-centric systems typically rely extensively on information received from the network for proper operation. Of critical importance is the ability of the network to support the transmission of the correct information in a timely manner to the various systems involved in an operation.

Furthermore, a complex system under test may be a system of systems (SoS). This means that each of the systems that comprise the SoS is controlled or operated independently by a different stakeholder (for example, Army, Navy, Air Force). A SoS therefore involves the integrated operation of large scale systems from multiple organizations to accomplish more complex missions. This results in new and unique challenges for testing [3], such as testing across organizational boundaries with no single organization being responsible for the SoS performance, as well as dealing with heterogeneous systems within the SoS that present interoperability challenges or lead to unknown interactions.

While some network-centric systems may rely on small scale and local networks and are entirely operated by a single stakeholder or organization, of particular interest in the context of PATFrame are network-centric systems that involve multiple stakeholders. In the latter case, net-centric systems may be considered under the umbrella of SoS, since the information that they rely on may be provided by multiple stakeholders, while each of the individual systems is under the control of a different stakeholder.

Once the SUT boundary is defined by identifying the system (or system of system) for which the performance and effectiveness should be tested, one may then distinguish the SUT from the environment in which it operates. The environment may be characterized by external influences or constraints upon the SUT that may affect the operation of the SUT.

Based on the above definitions, we introduce a framework for characterizing the boundaries of complex systems under test. Figure 1 shows the three axes that were identified as relevant. The two horizontal axes characterize the SUT, whereas the vertical axis characterizes the interaction of the SUT with the environment in which the SUT operates.

For the SUT, one of the axes characterizes the level of autonomy, and the other characterizes the complexity of the SUT in terms of the stakeholder diversity. We consider the boundary cases for each axis. For the autonomy levels, Figure 1 indicates two levels: human-operated and fully autonomous, AI-based system. As for the complexity of the SUT, we consider a single system (S) which is owned by a single stakeholder, or a system of systems (SoS) which is owned by multiple stakeholders.

For the vertical axis that represents the operational environment of the SUT, we characterize it by net-centricity, i.e. by the reliance of the system on information controlled by other stakeholders and communicated via a network infrastructure. The levels of net-centricity considered are “none”, which means that the SUT does not rely on a network, and “SoS”, which means that the SUT relies on information provided by multiple different stakeholders through a network infrastructure.

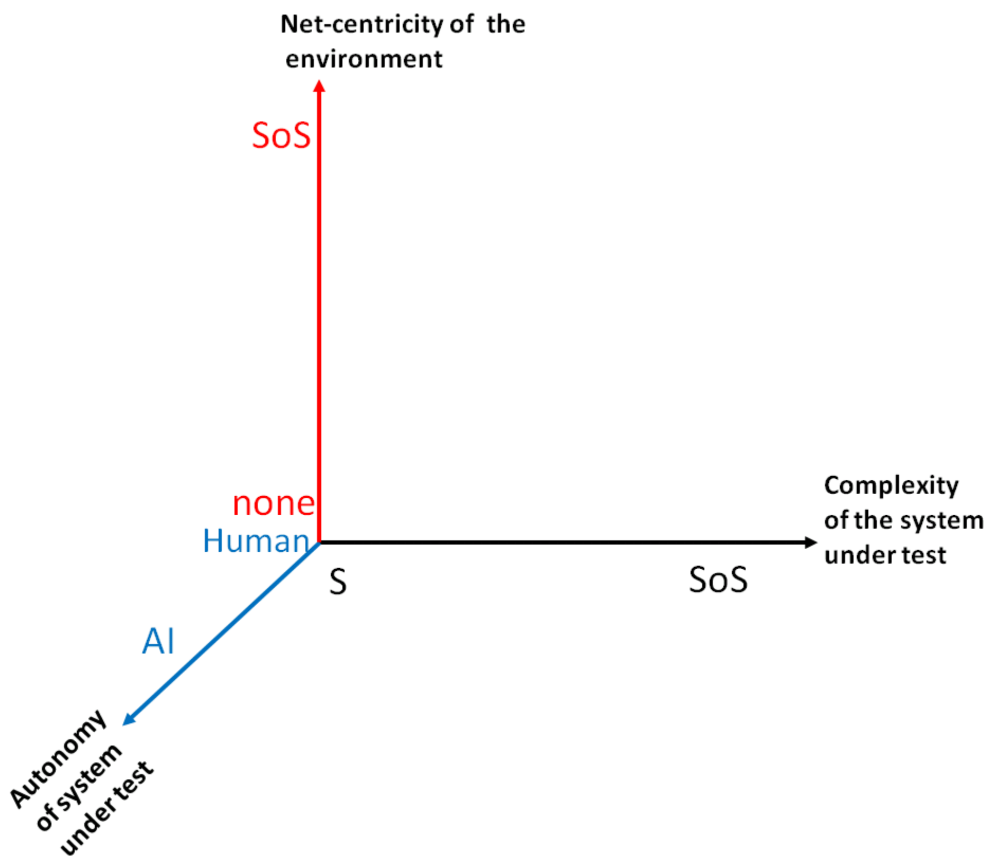

Figure 1: Framework for characterizing the SUT and its operational environment.

Next, we examine the boundaries that characterize the SUT and its environment as defined by the three axes. The boundaries correspond to the cube shown in Figure 2.

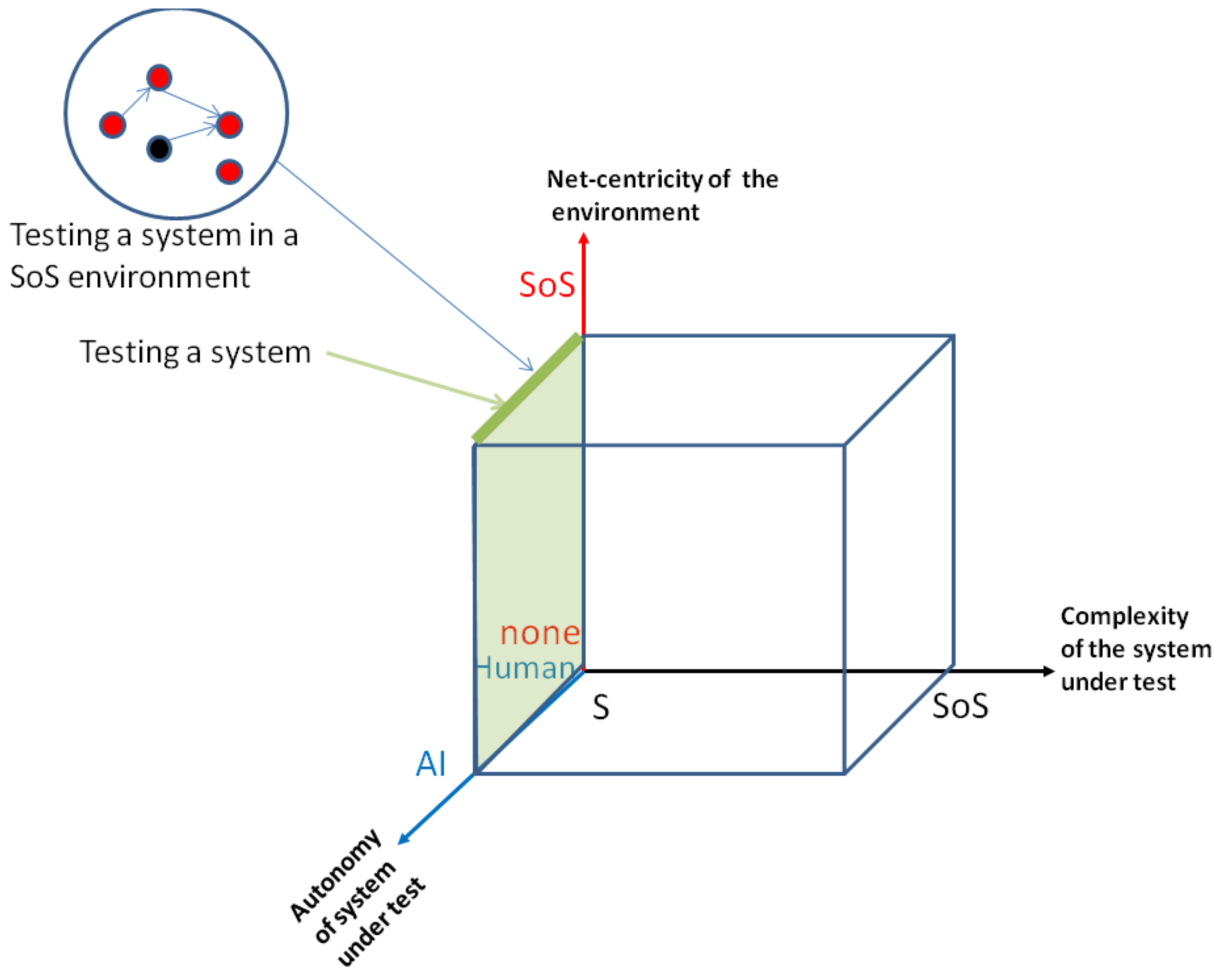

Figure 2: Boundaries that characterize the SUT and its environment, as represented by cube. The black circle represents a SUT and the red circles represent other systems in the net-centric environment.

First we consider the case of testing a single system under the control of a single stakeholder. This corresponds to the case where the complexity of the SUT is "S", as represented by the shaded plane in Figure 2. The origin of the frame in Figure 2 corresponds to the case of testing a traditional, human operated system in isolation, i.e. in an environment where there is no net-centric operation that involves other stakeholders. The highlighted line at the top of the shaded plane corresponds to the case of testing the system in a net-centric, SoS environment. The latter case is represented by the scenario in Figure 2, which shows a single SUT as a black circle, operating in a networked environment consisting of other systems represented by the red circles. The red systems form a SoS and may be controlled by multiple stakeholders.

Next, we consider the case of testing a SoS, which is a complex system controlled by multiple stakeholders. Therefore, testing a SoS involves joint efforts from various stakeholders such as the Army, Navy and Air Force.

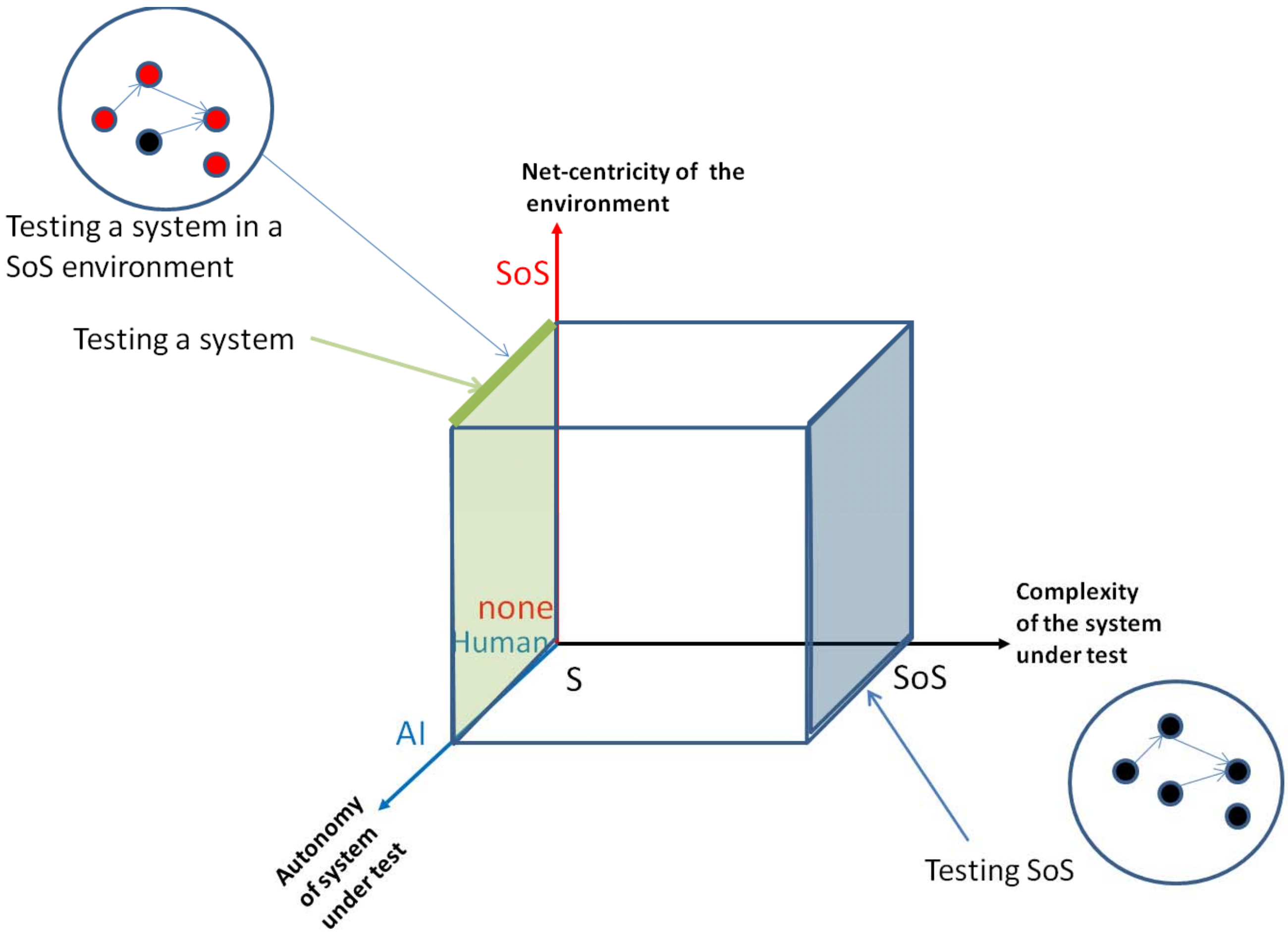

Figure 3: Distinction among testing a system (green shaded plane) and testing a SoS (blue shaded plane). The black circles correspond to the SUT.

Figure 3 shows the boundaries corresponding to SoS testing as highlighted in blue. A special case of SoS testing is also shown as a network of black circles representing the entire SoS under test. In this case, the environment external to the SUT does not involve additional network centric interactions with the SoS. Testing the entire SoS may then be considered to be testing the mission.

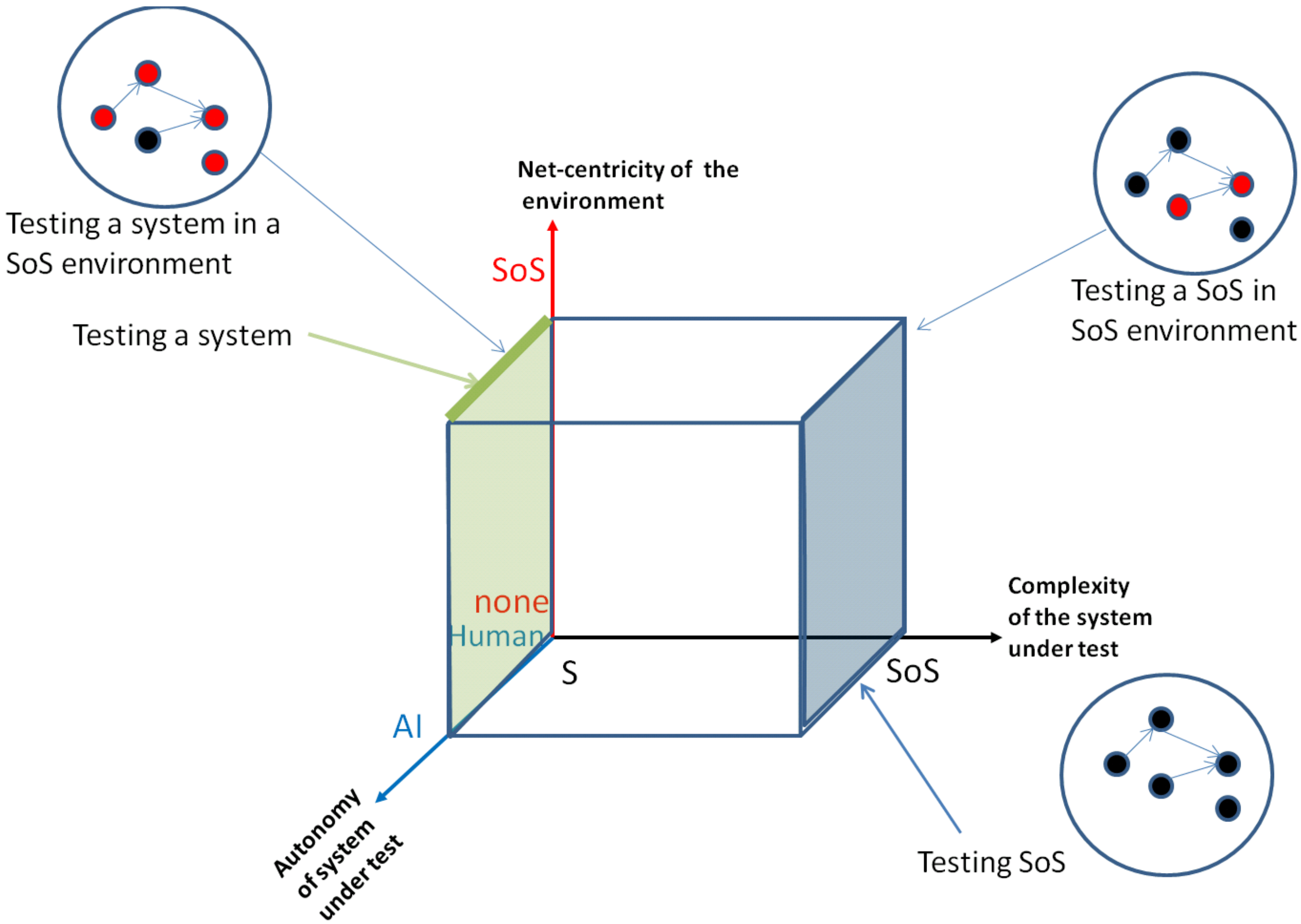

Figure 4: Testing a system of systems (SoS) in a system of systems (SoS) environment.

Another special case of SoS testing is shown in Figure 4 (testing a SoS in SoS environment). In this case, a portion of the SoS is identified as the SUT (black circles) and the environment also includes SoS nodes (red circles) that exert external influences upon the SUT. Therefore, the net-centricity of the environment is characterized as “SoS” in this case.

Besides identifying a distinction among testing a system versus testing a system of systems, a distinction is often made among testing network-centric systems versus autonomous systems. For instance, the DoD distinguishes among two testing investment areas: NST (Net-centric Systems Test) and UAST (Unmanned and Autonomous Systems Test) [4, 5].

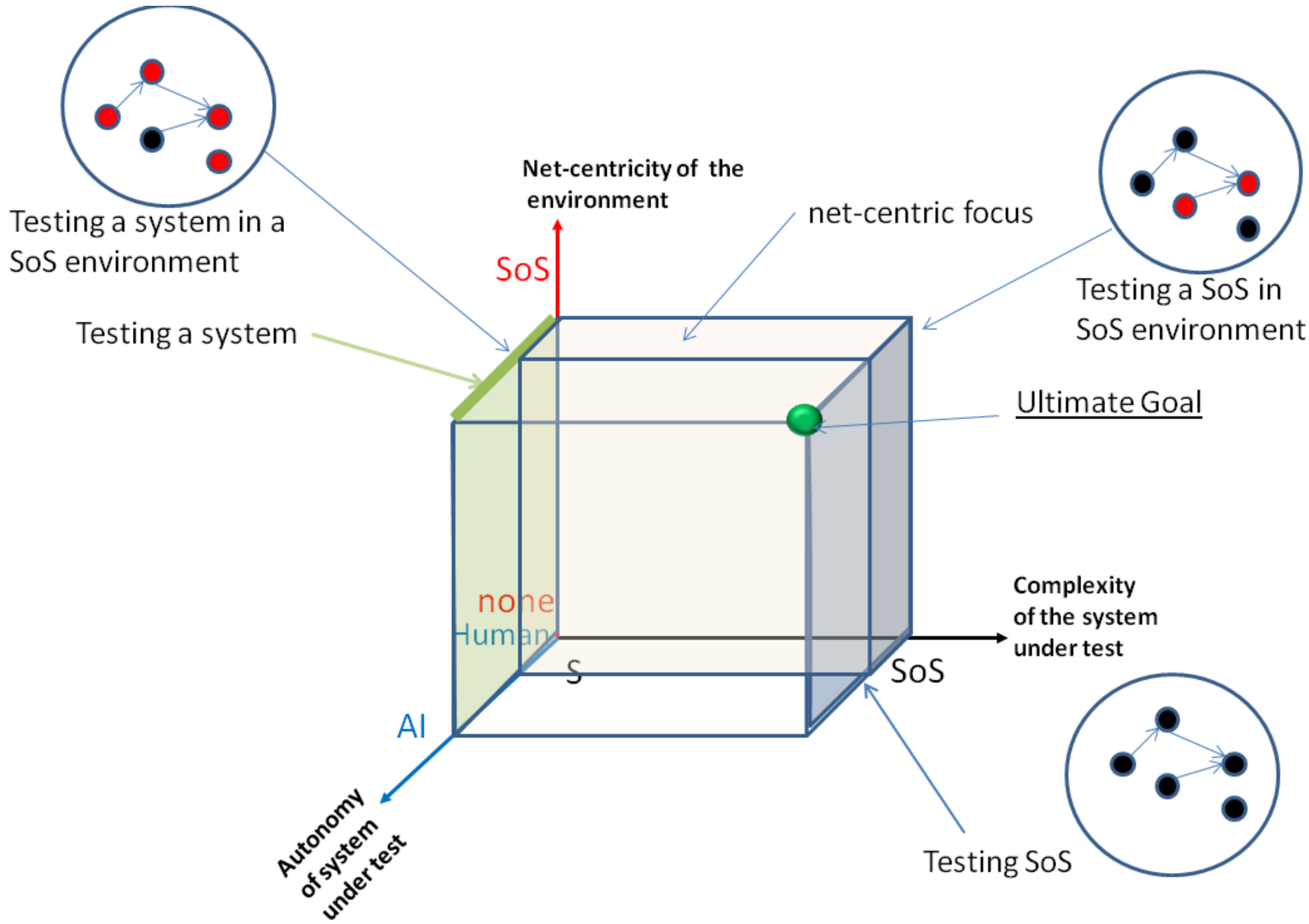

Figure 5: Net-centric Systems Test (NST) focus area.

The net-centric testing focus area is highlighted in Figure 5. This area is concerned with testing systems or networked system of systems operating in a networked environment; it is not specifically concerned with autonomy considerations.

The ultimate goal of PATFrame is to provide a framework for testing complex system of systems where the constituent systems may be autonomous, and operating in a networked environment with external influences.

The UAST focus area is shown in Figure 6 to be complementary to the NST area, and primarily concerned with testing systems and system of systems with high levels of autonomy. For example, autonomous systems testing may involve aspects that are not necessarily handled by solely considering net-centricity, such as autonomous reconfiguration upon encountering a failure mode. The difficulty of testing is often increased with higher autonomy levels, due to new challenges such as adaptive or unpredictable system behavior [1, 5].

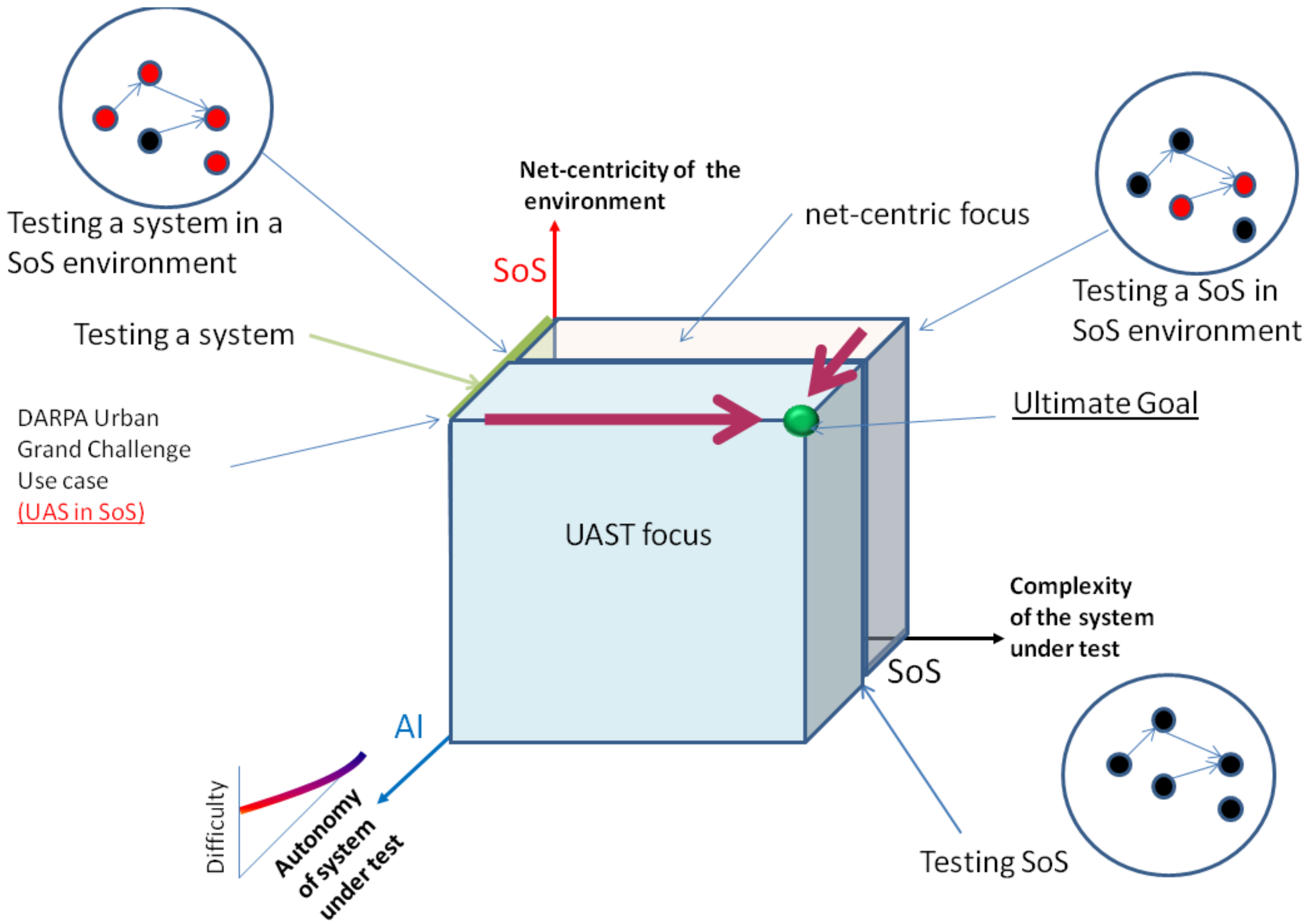

Figure 6: Unmanned and Autonomous Systems Test (UAST) focus area.

An example of an autonomous systems testing use case is the 2007 DARPA Urban Challenge [6]. As shown in Figure 6, this use case deals with testing single vehicles operating in a SoS environment. The net-centricity of the environment is characterized as a SoS if the vehicle relies on information received from externally controlled sources such as GPS or other vehicles.

The ultimate goal of PATFrame is to provide a decision support system for testing system of systems with autonomous constituent components and operating in a network centric SoS environment with external dependencies. This ultimate goal may be reached from either the UAST or NST focus areas (shows by arrows in Figure 6). Intermediate goals may include testing a single autonomous system in a network centric SoS environment and testing an autonomous system of systems assuming the stakeholders for the joint testing span the entire SoS.

In summary, this paper presented a framework for characterizing a complex system under test and its operational environment. Several testing paradigms were identified using this framework, such as the distinction among testing a system in a SoS environment and testing a SoS. Each of these paradigms may require a different testing approach or method in PATFrame. Mapping a SUT and its environment to this framework may therefore support the identification of an appropriate testing paradigm and associated methods. For instance, testing an entire SoS operation may necessitate joint, multi-stakeholder mission based simulations whereas in the case of a single system the operational SoS environment may be treated as an external constraint.

References

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