Towards an Agent-Oriented Approach for Requirements Engineering in the Digital Era

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Abstract

As technology systems increasingly acquire human-like capabilities, requirements engineering frameworks need to adopt abstractions that are rich enough to support analysis of the complex relationship between systems and the social environment. The *i** framework for social modeling, with its intentional, strategic actor abstraction, could provide a useful foundation. We suggest areas for extending agent-oriented modeling to respond to the challenges of the digital era, including the modeling of human values, emotional behavior, learning, and complex identities.

Keywords

Requirements engineering, agent-oriented, social actor, iStar, values, emotion, learning, identities

1. Abstractions in Requirements Engineering

Unlike other areas of software engineering, requirements engineering (RE) focuses not on the technology system per se, but on the relationship between the system and the world. An important tenet of RE is to not prejudge the technology solution, when the problem is not yet well understood. One needs to build the right system, as well as to build it right. RE methods, techniques, and frameworks provide guidance and tools to understand the problem in context, identify potential technology-enabled solutions, and to avoid solving the wrong problem [1, 2].

Requirements modeling frameworks typically offer a small number of core abstractions to focus attention in RE efforts, including requirements discovery, elaboration, negotiation, prioritization, etc. These abstractions greatly simplify one's understanding of the world, by considering only the bare essentials. Early RE frameworks adopted activity (process) [3] and data flows [4] as core abstractions. Object-oriented frameworks [5] adopted the (interactive) object as the core abstraction. What is considered essential and therefore to be captured in the core abstractions has evolved over time as capabilities of technology systems advanced, altering the kinds of relationships that systems have with their environments. In the digital era, technology systems are acquiring increasingly human-like capabilities, and engaging with humans in ever richer, human-like relationships. What kinds of core abstractions would be suitable for conducting RE so that technology systems would address human needs in today's complex digitally-infused social reality?

The *i** framework [6] was motivated by the need to understand and analyze social context in order to arrive at viable technology solutions. It proposed the social actor (or agent) as a core abstraction for modeling [7, 8], inspired by the agent abstraction in AI [9]. In this paper, we reexamine the agent-oriented approach to RE taken in *i**, and suggest areas for enhancements to respond to RE challenges in the digital era.

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2. The *i** framework for Social Modeling

Modern life is predicated on extensive networks of human and technological services and intermediaries. The initiator of an innovation seeks to offer gains to some target community (e.g., customers) with the support of other stakeholders (e.g., employees, shareholders, regulators). A successful innovation offers a new pathway in an enhanced or modified network that would be favored over previously existing pathways by the affected parties. *i** modeling can be used to analyze the network of dependencies among human actors and technologies in order to arrive at system requirements that address the needs and concerns of all relevant stakeholders.

Suppose you want to have dinner. You can prepare the meal yourself, or you can have someone else prepare it for you. In the latter case, you can specify how the meal is to be prepared, giving instructions as in a cooking recipe, or you can leave it up to your personal chef.

In *i**, when Actor A depends on Actor B for some goal to be accomplished, e.g., dinner be ready, without specifying how, that is modeled as a *goal dependency*. On the other hand, if A expects B to perform a task in a specified way, that is modeled as a *task dependency*. The distinction allows the modeler to express the freedom that B has in meeting A's expectations.

Actor A may want the meal to be tasty as well as healthy. These would be modelled as *softgoal dependencies* on B. A softgoal specifies a quality that would need to be elaborated and refined until there is a mutual understanding between A and B. Finally, a *resource dependency* is used to indicate that one actor depends on another for the availability of some material or informational entity.

An *i** Strategic Dependency (SD) model is a network of such dependencies among actors. An *i** *actor* is intentional (has goals, beliefs, and commitments), autonomous (has freedom to choose among alternative ways for achieving goals), social (depends on others but also depended upon by others), and strategic (chooses alternatives that are in its own best interest) [7]. An actor can take advantage of opportunities by depending on others, but becomes vulnerable at the same time.

The *i** Strategic Rationale (SR) model is used to describe the reasoning that each actor has about its goals and softgoals, and the alternative ways for achieving them. Each alternative is elaborated through refinement into subgoals, tasks, resources, and in many cases, eventually dependencies on other actors. Softgoals are operationalized into tasks once they are sufficiently refined.

The interconnected network of dependencies and rationales can be analyzed using graph propagation algorithms [10] to determine which and whose goals are met or not met for each set of alternative design options. In the digital era, your personal chef might be a robot, or merely a mobile app orchestrating your kitchen devices in your smart home. There are numerous design options with different relationships between humans and machines. Domain knowledge could be brought to bear to guide the generation and exploration of innovations and technology options that are more likely to gain acceptance by all relevant parties. Knowledge about frequently encountered goals and how they can be achieved (through refinements and operationalizations) can be collected in catalogs to facilitate reuse, as in the treatment of non-functional requirements [11, 12, 13][2].

Crucially, as with the core abstractions in earlier major RE frameworks such as SADT [3], DFD [4], and OOA [5][3], the *i** actor does not prejudge the human-machine boundary. The *i** actor could well be human, machine, or any unspecified mix [8]. The *i** actor is an external characterization, independent of internal construction. This actor abstraction draws inspiration from the knowledge level [9], originally intended for characterizing artificial agents, and the intentional stance [15], intended for understanding humans. This neutrality with respect to the human-machine distinction allows questions about what to automate to be raised and reasoned about during the RE process. Further, the same actor abstraction can equally be used to model individuals, organizations, or any coherent social entity on the same terms, again without prejudging their internal make-up, which may include human and technology elements. This abstraction enables sociotechnical analysis without prior separation of the social and the technical [16]. Many extensions and adaptions of the *i** framework has been developed for RE and for other usage contexts [17, 18].

[2] The cataloging of means-ends knowledge for reuse is not specific to agent-orientation, but rather follows from goal-oriented RE frameworks (e.g., NFR Framework [11], KAOS [14]).

[3] While many requirements modeling techniques model the system in its environmental context or include stakeholder perspectives (e.g., scenarios, use cases, problem frames, business process modeling notations), they do not necessarily facilitate reconsideration of alternate placements of the human-machine boundary.

3. Challenges for Requirements Modeling in the Digital Era

Early pioneering RE techniques were created in the days of routine data processing. Today, digital technologies are deeply embedded in our personal, social, and work lives. They acquire capabilities by learning from broad-based data sources as well as from our individual digital traces. They can observe our facial expressions, body language, listen in on our conversations, and respond in kind [19]. They can exploit our deeply held beliefs and even reshape them [20, 21]. They are co-workers who acquire new skills by watching us, then take over when they perform better than us [22].

The challenges for RE today include dealing with machines capable of interacting with us at an emotional level [23, 24], recognizing and exploiting our cultural predispositions and values [25, 26], and imitating our behaviors, sometimes inappropriately [27]. This calls for a sufficiently expressive modeling abstraction that can be used to articulate a desired vision [28] in today's rich human social context. The envisioned "to-be" model should not prejudge the human-machine divide, so as to allow RE activities to explore the space of alternatives and their implications for diverse stakeholders.

As machines increasingly interact with us on human-like terms, an agent-oriented modeling approach drawing on philosophical [15] and technical [9] foundations could provide a useful starting point. Recent literature on digitalization and on RE would suggest that an RE framework for the digital age will need to include the following considerations.

Human Values. How does one recognize and reconcile the diversity of human values at play among individuals, communities, and cultures when considering proposed digital innovations? What values are appropriate for incorporating into automated systems? [29, 30, 31] How does one avoid the pitfalls of incorporating inappropriate values [32].

Emotions. Intuition and emotion drive human behavior and decisions more than rational deliberation [33]. How does one include the effects of sentiments and emotions in analyzing the reconfiguration of social relationships arising from a digital innovation? How does one characterize emotional behavior exhibited by humans and machines at a suitable level of abstraction for requirements analysis? [34, 35, 36, 37].

Learning and knowledge acquisition. Humans and machines learn from sensory experience as well as from symbolic representations and interactions. They also learn to adapt to each other. How does an RE framework take continuous learning into account, considering the great diversity of ways in which humans and machines learn and acquire knowledge? [38, 39, 40]

Complex identities. Individuals have multiple identities - professional, social, familial, political, cultural, national, etc. [41, 42]. Companies project brand identities, product identities, and social responsibility identities. Identities may complement or compete with each other, even as they become closely associated, e.g., as embodied in a single person or a company. As humans augment themselves with technologies and technologies systems take on human qualities, their identities become entangled. [43, 44, 45]. How does one account for interactions among diverse identities when exploring digital innovations?

Dynamics. As the world changes, humans as well as technology systems adapt or evolve to respond to changing conditions [46, 47]. Values, emotional responses, beliefs, goals, and ways for achieving goals, social relationships, etc., can all change over time. How can an RE framework be used to adequately represent and reason about various types of change?

Temporal framing. Digital innovations often engage with actors operating on different time frames and scales and experiencing different rates of change. These actors tend to have different priorities and conflicting interests. Decisions that make sense in the short term may not make sense in the long run [48, 49]. Under time pressure, behaviors tend to be driven by impulse and emotion, as rational deliberation is cognitively demanding [50]. Cultural values may be stable yet variable over a longer time frame. An actor's options for decisions and actions are constrained, but sometimes also enabled, by past events, actions, and commitments [51]. Learning implies cumulative effects over time. The challenge for RE would be to adopt suitable simplifying frameworks to handle the complex dynamics and temporal framing in today's social realities.

Grounding in reality. Humans can have abstract thought but must ultimately be grounded in reality. Many software systems today have tight feedback loops that reach into the environment, so that their behaviors can self-correct and adapt or evolve to accommodate uncertainty as the environment changes

[52]. Requirements models, even at a high level of conceptual abstraction, can nevertheless provide for connections to the "real world" [53, 54]. What constitutes reality, however, depends on an actor's viewpoint. How does one, during requirements analysis, acknowledge the different realities faced by different actors and how they choose to connect to those realities?

Continuous development in humans and in systems. In the digital era, software systems undergo rapid cycles of change [55]. Yet humans also undergo continuous development in their personal and professional lives, as they co-evolve with their technologies [56]. Organizational roles and skill sets are frequently redefined. In the digital era, adaption and evolution in humans and in systems become increasingly intertwined. Humans in the "Usage World" [57] today are much augmented by digital tools. Yet digital technologies (in the "System World" [57]) rely heavily on human social processes and structures for ongoing support and development ("Development World" [57]). Systems developers in turn rely on tools ("System World" from the viewpoint of tool developers) and processes (e.g., DevOps and MLOps), which themselves are undergoing continuous innovation. There are intricate dependencies between software ecosystems and larger societal ecosystems. Systems designers and developers engage with social actors in the usage world not only through products and services, but also in terms of values, emotions, and learning. An RE framework in the digital era will need to account for the complex couplings among the many "worlds".

4. Towards Next-Generation Agent-Oriented RE Frameworks

Digital technologies, including the latest advances in AI, are transforming society and human lives. Current RE frameworks, including i* (with its limited agent-oriented abstraction), are ill-equipped to support analysis of the complex transformations that technologies are inducing in human and social relations, intended or otherwise. Nevertheless, an agent-oriented approach as exemplified by *i** offers a potential starting point for exploring the next-generation of RE frameworks. For example, the social actor abstraction in *i** could potentially be extended to support analysis of complex social phenomena, such as affective relationships and conflicting values among actors of all types, ranging from fully human to fully automated, and at any level of aggregation. There is much to draw on from the social sciences and humanities, as well as from software engineering, AI, and systems sciences. A major challenge for RE research is to identify suitable abstractions that are simple enough to be used in professional RE practice yet rich enough to address the issues that matter.

5. References

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