

DAI Betwixt and Between: From "Intelligent Agents" to Open Systems Science

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Actors are introduced as primitives of concurrency -- computations consist of communications between actors, each of which has local information, and must communicate with other agents to access other information. Joint activity can result in conflicts, causing some activities not to be completed; degrees of self reliance and interdependence in activities are discussed. ORGs, organizational structures for large scale work, are an extension of actors, consisting of actors and of smaller ORGs. The passing of messages among the actors which are members of separate ORGs is most important to computation, and ORG boundaries are explained, along with a mechanism for maintaining them for effective communication. Conflict processing is done by forums, which provide all their information (mod individual filters) to all subscribers; these are used as arenas for negotiation.

I. Introduction

Open Systems Science focuses on robustness, manageability and scalability to solve problem in large scale open systems where the focus shifts from centralized systems toward decentralized ones, with an emphasis on conflict processing.

II. Actors

Actors are primitives of concurrency.

Precursors

In *pattern directed invocation* a pattern represents what is sought, and acts as an advertisement for work to be done -- unlike procedure directed invocation which directly specifies which procedure to use, it allows the computation to try out and choose alternatives.

Planner-69 was the first pattern directed planning language for "Intelligent Agent." It had forward chaining (if P then Q) and backward chaining (if Q is goal, make P subgoal). Backtracking was expedient, but moved the semantics away from pattern directed invocation. *Simula*, an OO programming language for sequential simulation of concurrent situations provided a new conceptual basis. In *Simula*, each simulated object kept track of its local state. *Smalltalk* was a more interactive version of *Simula* that made innovative use of OOP.

Properties of Actors

Causality is local in Actor computations, there is no global entity or process. Computation is accomplished by Actors sending communications to one another.

To communicate with actor A, we must have a *handle* (like an e-address) for A. When a communication arrives at an actor, the actions of the actor are determined by its current *behavior*. The actor can process the message using any **local** information available. The actor may concurrently

- make local decisions
- create more actors

- send more communications
- replace its behavior

All information exists in the form of actors, accessed only by sending messages along handles. The local information available to an actor consists of handles to other Actors, not the other actors themselves. Actor computations are orchestrations of concurrent message passes.

Activation ordering is a partial ordering on actor events. When a communication is sent by one actor (event₁) and received by another (event₂), these two events are ordered by the activation ordering "event₁ occurs before event₂". Another partial ordering is *arrival ordering* -- the order in which communications arrive at an actor.

A language-independent characterization of concurrent systems was developed using actors for *implementing* concurrency, instead of objects for *simulating* it.

Proofs

A *serializer* is an actor that processes the communications it receives in arrival order and can specify a different behavior for itself depending on its current behavior and the communication it has received. Suppose A is created having property P and if A has property P when it receives a communication, then it will have P when it processes the next communication. Then by actor induction, A will always have P.

Models

The lambda calculus can be strictly embedded as a special subtheory in the actor model -- the criterion of continuity (Scott) is satisfied by every function that can be defined by an actor system (Hewitt). The laws for actor systems are consistent; it is always possible to construct a global time for any computation that satisfies the actor laws (Clinger). The model used to prove this shows that multiple frames of reference are possible in actor systems; activation and arrival ordering of events remain consistent, regardless of frame of reference. If an activation or arrival ordering holds for two events, it will hold for all observers of these, if there is not an ordering, different observations might be made in different frames of reference.

III. Open Information Systems

In Planner-69 and Prolog, a closed world was assumed, this was too limited a view. An improved semantics of primitive actor behaviors was developed by Gul Agha, who also defined Act, a micro language for actor primitives. He extended the semantics of actor systems to analyze transitions on and the concurrent composition of configurations. A *configuration* is a snapshot of an actor system at one particular time, describing the local state of each actor, and what communications are currently in transit. Agha also worked on observation equivalence in actor systems and showed that modeling concurrent systems purely by input and output and ignoring local state was not enough. Agha presented an intuitive model.

The Role of Logic in Open Information Systems

One school of AI believes AI should be based on logic. Another believes that the uniform proof procedures must also have embedded procedural know-how.

A *microtheory* is a derivational calculus with a pre-specified automaton that can check the correctness of any individual derivation step, given only the step. Deductive inference is not adequate to decide important questions in OIS because indeterminacy is everywhere in the use of

shared resources -- *deductive indecision*. Deductive indecision refutes Kowalski's thesis that deductive logic can be used as a universal systems implementation language. The scope of use of deductive inference exactly coincides with the use of microtheories by participants. By focusing only on relationships internal to a microtheory, deductive inference fails to address larger issues of use of microtheories by OIS participants. Deductive inference alone is inadequate to process conflicts because processes which actually produce the outcomes are left out.

All conflicts are local in that they occur at a particular time/place among local participants. *Joint activity* is any potentially-concurrent, interdependent activities. Often there is no conflict, but the potential is there and joint activity introduces indeterminacy. So there can be no logical foundations for decision making in DAI, which limits the kinds of logical foundations that can be provided.

Self Reliant and Interdependent Activities

An activity is *self reliant* if it can be carried out using only local resources. Activities are *Interdependent* if they are dependent on each other. A system may be self-reliant in some activities and interdependent in others. Activities *conflict* if they interact in a way that prevents some of them from being completed. Self reliant and interdependent activities vary along:

- *late arriving information* -- may be received from ongoing activities elsewhere. Decisions made without this information may be flawed, but decisions cannot be put off forever.
- *multiple local authorities* -- enable participants to react immediately to changing circumstances, instead of consulting a nonlocal decision maker for each decision. Where conflicts arise, local authorities can immediately manage the changing circumstances. Joint activities of local authorities almost always conflict over the use of shared resources because each acts locally on its own information
- *division of labor* -- involves creation of subactivities to distribute work and locally focus efforts on a narrower range of joint activities. Subactivities often conflict over resources.
- *Arm's length relationships* -- enable participants to conceal their internal activities from other participants and increase their own robustness, manageability and/or scalability. While increasing self-reliance, arm's length relationships can increase severity of conflict because participants may develop entrenched, incompatible activities before conflict is discovered.

Self reliant and interdependent activities must be balanced.

IV. Organizing Large Information Agencies

Information Agencies are systems with human and computer components in which production of all artifacts is accomplished from digital specifications. They are distributed, concurrent, have interdependent and self reliant subsystems, so they are open systems.

Background and Objectives

Large scale work requires organization, it must be divided among many resources. All of these organizations operate concurrently, and their activities often affect one another. So negotiation becomes an essential activity in large scale work.

Relation of Actors to ORGs

ORGs introduce technical means for composing larger ORGs out of several smaller ones; they can be created by *budding* in which an actor can transform itself into an ORG. Every actor can function as a rudimentary ORG.

ORG Facilities

Organizations of restricted generality (ORGs) is an organizational structure for large scale work. ORGs represent an extension of the actor architecture providing support for organization.

- *operations facility* -- provides resources for authorized tasks: processing, storage, and communications. Every task processed by the system will require the use of each of these.
- *reporting facility* -- provides information for other facilities concerning the 'what' 'when' and 'which participants' of events. Useful for supporting the management facility and for monitoring and debugging.
- *membership facility* -- keeps track of the ORG population, creates new memberships, and terminates existing memberships as the ORG evolves. Each ORG is in control of its own memberships. An actor may be a member of several ORGs.
- *liaison facility* -- controls communications crossing the ORG boundary. *Reception* is a subfacility of liaison which fields communications sent to the ORG as a whole and directs them to appropriate internal recipients; it may be a distributed facility consisting of many actors working together so traffic passing through reception can be processed concurrently. TEAMS do not provide this. One reason for having ORGs is to modularize related concurrent activity, allowing management and re-organization in interdependent suborganizations. The liaison boundary represents an abstraction barrier for handles to actors that are members of different ORGs. ORGs can update member behavior without having to tell external actors which might have the handles of internal actors by replacing actual recipients of communications coming through the boundary.
- *management facility* -- controls the behavior of the ORG. It sets policies and procedures for ORG behavior. Responsible for paying resource charges (processing, communications, storage) and can manage ORG activities to effectively use these resources. When charges for resources used are received, they may be filled using internal resources, or with resources requested from other ORGs. Or it may stifle a subcomputation -- refuse to grant the request, or restructure its activities to make resources more accessible.

Teams of engaged activity and management (TEAMs) are suborganizations of an ORG that do not have a liaison facility, and so are more flexible, but have less control over communications between the TEAM and the rest of the containing organization. Most of what we say about ORGs applies to TEAMs.

One possible mechanism for maintaining ORG boundaries:

- Actors that manage communications from in an ORG to outside are *outsiders*. *Insiders* manage communications coming into an ORG from outside. Liaison facility manages insiders and outsiders.
- Actors send messages to each other, usually containing handles to other actors. There is a handle for the ORG as a whole, and an actor in the org is designated to handle this.
- To maintain a well-defined ORG boundary, any communication that passes through an ORG boundary will pass through liaison.
- An insider functions as a portal for messages coming in to some particular member; any actor handles these messages may contain are translated so they can be used in the ORG's internal context.
 - external handles to internal actors (always handles to other insiders in liaison) are replaced with direct handles to the internal actors themselves.
 - external handles to external actors (often handles to insiders in other ORGs' liaisons) are replaced with handles to outsider actors in the liaison facility of the recipient ORG. So messages to external actors will always be processed by outsider actors.
- An outsider performs the reverse translation for messages sent from inside the ORG out.
- This allows ORG boundaries to be implemented using normal actors, whose behaviors are to perform the appropriate translation and then forward the translated message. The translation is

supported through the liaison facility.

- For each actor mentioned in a communication, we must be able to determine if that actor is resident in the ORG, then find or create any needed liaison actors. If the communication is departing, insiders must be found or created and handles to outsiders of this ORG are replaced by the actual external handles. If the external actor is in another ORG, the external handle will be a handle to the insider in the other ORG. If communication is entering an ORG, handles to nonmember actors must be mapped to outsider handles (found or created) and handles to insiders of this ORG are mapped to internal handles for actors they represent.

Specialized ORGs

Transaction ORGs handle activity for which an ORG wants to delegate some of its management and resources. It will be dependent on its owning ORG for resources. The advantage of this is maximized concurrency and maintained modularity. Management of resources remains well distributed. Small scale and large scale projects can have different management objective while still being interdependent.

Project ORGs -- several ORGs pool resources in a suborganization to help organize common work without compromising modularity.

V. Conflict Processing In Information Agencies

Self Reliance and Interdependence are potential sources of conflict -- interactions that cause some activities not to be completed.

Forums

Forums are a means for information to be shared with subscribers. Each subscriber to a forum can receive all sharings at the forum, each has a filter so that it only receives the sharings it wants. Each sharing consists of a message and a respondent responsible for responding to requests concerning the sharing. A forum is used as an arena for negotiation. The most common conflict results from unintended interactions in ongoing joint activities. Forums are commonly used to explore the nature of these interactions. We don't presume all conflicts can or should be resolved automatically by telecomputer equipment.

Related Work: Blackboard Architecture

The blackboard architecture has a global database, independent knowledge sources that generate solution elements, and a scheduler to control knowledge source activity. Forums use none of these, there is no global database, information resources are not independent, and there is no scheduler for a forum to control subscribers.

Related Work: Conflict Processing

Forums do not assume that in competitive situations each party has only their own benefit in mind. Conflict typically is not due to parties having different, possibly partial or incorrect theories of how to achieve an optimal solution. Differences usually do not depend on having different conflict resolution strategies, but simply on unforeseen interactions.

Related Work: Negotiation

Designer-Fabricator-Interpreter research develops a system for aiding negotiations between designers and fabricators, overseen by an arbitrator. If the 'super agent' notices a deadlock, it intervenes and informs one agent that the other will agree if a change is made; it has final say on the

importance of each issue. Forums are not overseen by a super agent, but forums for resolving conflicts may produce new conflicts, and it would be useful to have an appropriate kind of expert moderation handy.

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