# What Is Commitment? Physical, Organizational, and Social (Revised)

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**Abstract.** This paper uses Participatory Semantics to explicate commitment. Information expresses the fact that a system is in a certain configuration that is correlated to the configuration of another system. Any physical system may contain information about another physical system.

For the purposes of this paper, physical commitment is defined to be information pledgedabout physical systems (situated at a particular place and time). This use of the term physical commitment is currently nonstandard.

Note that commitment is defined for whole physical system; not just a participant or process.

Organizational and social commitments can be analyzed in terms of physical commitments. For example systems that behave as scientific communities can have commitments for monotonicity, concurrency, commutativity, pluralism, skepticism, and provenance.

Speech Act Theory has attempted to formalize the semantics of some kinds of expressions for commitments. Participatory Semantics for commitment can overcome some of the lack of expressiveness and generality in Speech Act Theory.

## 1 Introduction

This paper uses Participatory Semantics [15] as formalism within which to explicate commitment. Participatory Semantics makes use of participations that are 4 dimensional regions of space-time. Participations include both happenings (regions in which things happen, e.g., purchasing, communicating, etc) and participants (regions for things that participate, e.g., people, XML expressions, etc). Participatory Semantics derives from concepts in physics (e.g. quantum, relativistic).

## 2 Information

Information expresses the fact that a system is in a certain configuration that is correlated to the configuration of another system. Any physical system may contain information about another physical system.

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### 2.1 Information Is Necessarily Incomplete

Although Einstein was one of the first to formulate the necessary incompleteness of quantum physics, he never fully accepted it. Chris Fuchs [9] summed up the reality of the necessary incompleteness of information in quantum physics as follows:

> *"Incompleteness, it seems, is here to stay: The theory prescribes that no matter how much we know about a quantum system—even when we have maximal information about it—there will always be a statistical residue. There will always be questions that we can ask of a system for which we cannot predict the outcomes. In quantum theory, maximal information is simply not complete information Caves and Fuchs [5]. But neither can it be completed"*

The kind of information about the physical world that is available to us according to [9] is *"the potential consequences of our experimental interventions into nature"* which is the subject matter of quantum physics.

### 2.2 Information Is Relational

According to Relational Quantum Physics [18], the way distinct physical systems affect each other when they interact (and not of the way physical systems "are") exhausts all that can be said about the physical world. The physical world is thus seen as a net of interacting components, where there is no meaning to the state of an isolated system. A physical system (or, more precisely, its contingent state) is reduced to the net of relations it entertains with the surrounding systems, and the physical structure of the world is identified as this net of relationships. In other words, *"Quantum physics is the theoretical formalization of the experimental discovery that the descriptions that different observers give of the same events are not universal"*.

The concept that quantum mechanics forces us to give up the concept of a description of a system independent from the observer providing such a description; that is the concept of the absolute state of a system. *I.e., there is no observer independent data at all.* According to Zurek [25], *"Properties of quantum systems have no absolute meaning. Rather they must be always characterized with respect to other physical systems"*.

Does this mean that there is no relation whatsoever between views of different observers? Certainly not. According to Rovelli [23] *"It is possible to compare different views, but the process of comparison is always a physical interaction (and all physical interactions are quantum mechanical in nature)."*

## 3 Actors and Events

Actors are the universal primitives of concurrent digital computation. In response to a message that it receives, an Actor can make local decisions, create more Actors, send more messages, and designate how to respond to the next message received. A Serializer is an Actor that is continually open to the arrival of messages. Messages sent to a Serializer always arrive although delivery can take an unbounded amount of time. (The Actor model can be augmented with metrics.)

*Unbounded nondeterminism* is the property that the amount of delay in servicing a request can become unbounded as a result of arbitration of contention for shared resources *while still guaranteeing that the request will eventually be serviced.*

Arguments for unbounded nondeterminism include the following:

- There is no bound that can be placed on how long it takes a computational circuit called an Arbiter to settle.
  - Arbiters are used in computers to deal with the circumstance that computer clocks operate asynchronously with input from outside, "e.g..", keyboard input, disk access, network input, "etc."
  - So it could take an unbounded time for a message sent to a computer to be received and in the meantime the computer could traverse an unbounded number of states.
- Electronic mail enables unbounded nondetermism since mail can be stored on servers indefinitely before being delivered.
- Communication links to servers on the Internet can be out of service indefinitely.

This section focuses on just those events that are the arrival of a message sent to an Actor.

### 3.1 Activation Ordering

The activation ordering ($-\approx\rightarrow$) is a fundamental transitive ordering that models one event activating another (there must be energy flow from an event to an event which it activates).

### 3.2 Arrival Orderings

The *arrival ordering* of an Actor x($-\mathrm{x}\rightarrow$) models the (total) ordering of events in which a message arrives at x. Arrival ordering is determined by arbitration in processing messages (often making use of arbiters).

Hewitt [11], and Hewitt and Agha [1], and other published work argued that mathematical models of concurrency did not determine particular concurrent computations as follows: The Actor model makes use of arbitration for determining which message is next in the arrival ordering of an Actor that is sent multiple messages concurrently. For example *Arbiters* can be used in the implementation of the arrival ordering of an Actor which is subject to physical indeterminacy in the arrival order.

In concrete terms for Actor systems, typically we cannot observe the details by which the arrival order of messages for an Actor is determined. Attempting to do so affects the results and can even push the indeterminacy elsewhere. Instead of observing the internals of arbitration processes of Actor computations, we await outcomes. Physical indeterminacy in arbiters produces indeterminacy in Actors. The reason that we await outcomes is that we have no alternative because of indeterminacy.

According to Fuchs[9], quantum physics is a theory whose terms refer predominately to our interface with the world. It is a theory not about observables, not about *beables*, but about *'dingables' . We tap a bell with our gentle touch and listen for its beautiful ring.*

The semantics of indeterminacy raises important issues for autonomy and interdependence in information systems. In particular it is important to distinguish between *indeterminacy* in which factors outside the control of an information system are making decisions and *choice* in which the information system has some control.

It is not sufficient to say that indeterminacy in Actor systems is due to unknown/unmodeled properties of the network infrastructure. The whole point of the appeal to indeterminacy is that aspects of Actor systems can be *unknowable*.

### 3.3 Combined Ordering

The combined ordering (denoted by $\rightarrow$) is defined to be the transitive closure of the activation ordering and the arrival orderings of all Actors. The combined ordering is obviously transitive by definition.

For all events $e_1$, $e_2$ if $e_1 \rightarrow e_2$, then the time of $e_1$ precedes the time of $e_2$ in the frame of reference of every relativistic observer.

*Law of Strict Causality for the Combined Ordering*: For no event e does $e \rightarrow e$.

### 3.4 Discreteness

Discreteness captures an important intuition about computation: it rules out counter-intuitive computations in which an infinite number of computational events occur between two events *(à la Zeno)*.

The property of Finite Chains Between Events in the Combined Ordering is closely related to the following property:

*Discreteness of combined ordering:* For all events $e_1$ and $e_2$, the set $\{e|e_1 \rightarrow e \rightarrow e_2\}$ is finite.

**Theorem 1 (Clinger [6]).** *Discreteness of the combined ordering is equivalent to the property of Finite Chains Between Events in the Combined Ordering* (without using the axiom of choice.)

We know from physics that infinite energy cannot be expended along a finite trajectory. Therefore, since the Actor model is based on physics, the Discreteness of the Combined Ordering was taken as an axiom of the Actor model[1].

[1] Discreteness of each of the Arrival Orderings and discreteness of the Activation Ordering together do not imply Discreteness of Combined Ordering *even if there is no change in behavior* (see appendix).

The above described Actor event structures can be used as the basis to construct a denotational model of Actor systems as described in the next section.

## 4 Denotational Semantics

The task of *denotational* semantics is to construct denotations for concurrent systems that are all the possible behaviors that can be exhibited by the system.

We can use Actor event *diagrams* to help construct denotations where an Actor event diagram is just an initial history of the evolution of a concurrent system making use of the combined ordering.

### 4.1 Domain of Timed Actor Computations

Related to the work of Clinger[6], we will construct an $\omega$-complete computational domain for Actor computations[2]. In the domain constructed here, for each event in an Actor computation, there is a delivery time which represents the time at which the message is delivered such that each delivery time satisfies the following conditions:

1. The delivery time is a positive rational number that is not the same as the delivery time of any other message.
2. The delivery time is more than a fixed $\delta$ greater than the time of its activating event. It will later turn out that the value $\delta$ of doesn't matter. In fact the value of $\delta$ can even be allowed to decrease linearly with time to accommodate Moore's Law.

The Actor event timed diagrams form a partially ordered set $<$ TimedDiagrams, $\leq>$. The diagrams are partial computation histories representing *"snapshots"* (relative to some frame of reference) of a computation on its way to being completed. For $\mathrm{d1}, \mathrm{d2} \in \mathrm{TimedDiagrams}$, $\mathrm{d1} \leq \mathrm{d2}$ means d1 is a stage the computation could go through on its way to d2.

The completed elements of TimedDiagrams represent computations that have terminated and nonterminating computations that have become infinite. The completed elements may be characterized abstractly as the maximal elements of TimedDiagrams. Concretely, the completed elements are those having no pending events.

**Theorem 2.** TimedDiagrams *is an $\omega$-complete domain of Actor computations i.e.,*

[2] $\omega$-complete means that limits exist. The work here stands in contrast to [6] which constructed an $\omega$-complete power domain from an underlying incomplete diagrammatic domain, which did not include time. The advantage of the domain TimedDiagrams constructed here is that it is physically motivated and the resulting computations have the desired property of $\omega$-completeness (therefore unbounded nondeterminism) which provides guarantee of service.

1. If D $\subseteq$ TimedDiagrams is directed[3] , the least upper bound $\sqcup$D exists; furthermore $\sqcup$D obeys all the Actor laws.
2. The finite elements of TimedDiagrams are countable where an element x $\in$ TimedDiagrams is finite (isolated) if and only if D $\subseteq$ TimedDiagrams is directed and x $\leq \sqcup$D, there exists $d \in D$ with x $\leq$ d. In other words, x is finite if one must go through x in order to get up to or above x via the limit process.
3. Every element of TimedDiagrams is the least upper bound of a countable in creasing sequence of finite elements.

### 4.2 Power Domains

**Definition 1.** *The domain* $<$ Power[TimedDiagrams], $\subseteq>$ *(after Clinger [1981] with the* crucial difference *that in this work the domain TimedDiagrams is ω-complete) is the set of possible initial histories* M *of a computation such that*

*1.* M *is downward-closed, i.e.,*
*if* d $\subseteq$ M, *then*$\forall$d $\in$ TimedDiagrams, d $\leq$ d $\Rightarrow$ d $\in$ M
*2.* M *is closed under least upper bounds of directed sets, i.e. if* D $\subseteq$ M *is directed, then* $\sqcup$D $\in$ M

Note: Although Power[TimedDiagrams] is orderedby $\subseteq$, limits are not given by U. *I.e.*, $\forall$i, $M_i \subseteq M_{i+1} \Rightarrow U_{i\in\omega} M_i \subseteq \sqcup_{i\in\omega} M_i$

*E.g.*, If $\forall$i, $d_i \in$ TimedDiagrams and $d_i \leq d_{i+1}$ and $M_i = \{d_k | k \leq i\}$ then

$\sqcup_{i\in\omega} M_i = U_{i\in\omega} M_i \{\sqcup_{i\in\omega} d_i\}$

**Theorem 3.** Power[TimedDiagrams] *is an ω-complete domain.*

### 4.3 Denotations

An Actor computation can progress in many ways.

Let *d* be a diagram with next scheduled event e and X $\equiv \{e | e- \approx\!\rightarrow_{1-\text{message}} e\}$, Flow(d) is defined to be the set of all diagrams with d and extensions of d by X such that

1. the arrival all of the events of X has been scheduled where
2. the events of X are scheduled in all possible orderings among the scheduled future events of d
3. subject to the constraint that each event in X is scheduled at least $\delta$ after e and every event in X is scheduled at least once in every $\delta$ interval after that. (Please recall that $\delta$ is the minimum amount of time to deliver a message.) Flow(d) $\equiv$ d if d is complete.

[3] A subset A of a partially ordered set $< P, \leq>$ is called a *directed* subset if and only if A is not the empty set and if a, b $\in$ A, there exists a c $\in$ A with a $\leq$ c and b $\leq$ c (*directedness*).

Let S be an Actor system, $\mathrm{Progressions_S}$ is a mapping
Power[TimedDiagrams] $\rightarrow$ Power[TimedDiagrams]
$\mathrm{Progressions_S(M)} \equiv \mathrm{U_{d \in M} Flow(d)}$

**Theorem 4.** $\mathrm{Progressions_S}$ *is $\omega$-continuous.*

I.e., if $\forall \mathrm{i M_i} \subseteq \mathrm{M_{i+1}}$ then,

$$\mathrm{Progressions_S}(\sqcup_{\mathrm{i}\in\omega}\mathrm{M_i}) = \sqcup_{\mathrm{i}\in\omega}\mathrm{Progressions_S(M_i)}$$

Furthermore the least fixed point of $\mathrm{Progressions_S}$ is

$$\sqcup_{\mathrm{i}\in\omega}\mathrm{Progression_S^i}(\perp \mathrm{S})$$

where $\perp S$ is the initial configuration of S.

The denotation $\mathrm{Denote_S}$ of an Actor system S is the set of all computations of S. Define the *time abstraction* of a diagram to be the diagram with the time annotations removed.

**Theorem 5 (Representation Theorem).** *The denotation* $\mathrm{Denote_S}$ *of an Actor system* S *is the timeabstraction of*

$$\sqcup_{\mathrm{i}\in\omega}\mathrm{Progression_S^i}(\perp \mathrm{S})$$

Using the domain TimedDiagrams, which is $\omega$-complete, is important because it provides for the direct expression of the above representation theorem for the denotations of Actor systems by directly constructing a minimal fixed point. In future work it will be shown how the representation theorem can be used as the basis for model checking to verify properties of Actor systems. The previous sections on the Actor model provide a basis for grounding concurrent computation in space-time. This grounding provides part of the foundation for the next sections on commitment.

## 5 Commitment

Various notions of commitment have been proposed around the notion of *information pledged.*

### 5.1 What Is Physical Commitment?

For the purposes of this paper, a *physical commitment* PC is defined to be a *pledge* that certain *information* I holds for a *physical system* PS for a *space-time region* R. Note that physical commitment is defined for *whole physical systems*; not just a participant or process. Participants and/or processes might be entangled!

Let K be the expressed knowledge of physical commitment for how a large number of people interact with their information systems. The experience (e.g.

Microsoft, the US government, IBM, etc.) with respect to large software systems (where K consists of tens of millions of lines of documentation, code, and use cases) is that K is inconsistent. Such inconsistencies are addressed in Direct Logic [13], [12], [14].

The use of physical commitment here differs from the previous work of Bratman, Cohen, Durfee, Georgeff, Grosz, Huber, Hunsberger, Jennings, Kraus, Levesque, Nunes, Pollack etc. in that it is not founded on the notion of psychological beliefs, desires, intentions, and goals.

### 5.2 Physical Commitment and Contracts

A contract C is a *signed* (XML) expression for a *physical commitment* PC that pledges the signers S show certain parties $P_s$ behave. In the course of time the parties $P_s$ can fall into and out of compliance with the contract C.

Since C is a finite and of limited expressiveness there is a great deal of behavior by $P_s$ that is left unspecified or ambiguous by C. Given these limitations, it might be that C is clarified, amended, or even completely revised in the course of time.

Furthermore various participants might actually see things differently as to whether the parties $P_s$ are complying with C. For example violations might not be detected for some time or might not ever be detected. Participants who detect violations may or may not be members of $P_s$.

Also C might contain escape clauses such that the commitment might become trivialized. For example C might contain a time limit such that it is no longer in force after a certain time.

Sometimes some of the parties $P_s$ do not fulfill C or desire to deviate from C. In some cases violations are innocent, unintentional, or cannot reasonably be avoided. In other cases some members of $P_s$ may deliberately violate C perhaps even concealing what they are doing.

### 5.3 Organizational Commitments

Organizational commitments are physical commitments that are undertaken by organizations.

Organizational commitments can be represented in contracts by having an organization sign a contract as opposed to an individual. For example, it is common for organizations to sign executable code for computers which commits that the organization is the originator of the code.

Often an organization will not entrust its entire authority to just one signature. So a system of delegation is established in which another signature might be granted a limited amount of organizational authority. This can be accomplished by a contract signed by a higher authority delegating certain specified abilities to another signature. In many cases, this delegation can be revoked at a later time.

### 5.4 Social Commitments

Social commitments involving permissions and obligations have been the subject of previous research by [3], [4], [22], [8], [16], [19] and [20], etc.

[8] proposed that a social commitment can be characterized by the following attributes:

- *debtor*: owes the content to the *creditor*
- *creditor*: is owed the content by the *debtor*
- *content*: a temporal proposition that at every time instant has a truth value that can be one of the following: *undefined, true, or false.*
- *state*: which is obtained by the actions makeCommitment, setCancel, setPending and must be one of the following: *unset, pending, cancelled, fulfilled, or violated.*

Similarly in [24], a social commitment has attributes of *debtor, creditor, condition* the debtor is to bring about, and *organizational context.* A social commitment as characterized in the above work can be considered a special case of physical commitment (as defined in this paper) between information with the required attributes and the physical system of the *debtor* and *creditor* during the time periods in question.

### 5.5 Inconsistent Social Commitments

Social commitments are analyzed in terms of permissions, obligations, prohibitions, dispensations, and delegations in [17] where meta-policies are used to attempt to remove some inconsistencies. As an example, they describe the recent issue with the passage of the Medicare prescription drug bill in the United States:

$$\mathrm{USGovStaff(p)} \Rightarrow \mathrm{obligated(p, answerCongressionalQuery(p))}$$

$$\mathrm{USGovStaff(Foster)}$$

$$\mathrm{boss(p1, p2)} \wedge \mathrm{order(p1, p2, s)} \Rightarrow \mathrm{obligated(p, s)}$$

$$\mathrm{boss(Scully, Foster)}$$

$$\mathrm{order(Scully, Foster, \neg answerCongressionalQuery(Foster)}$$

The above example has Foster faced with inconsistent social commitments when he received a query from the congressional Democrats on the estimated cost of the Medicare prescription drug bill since

$$\mathrm{obligated(Foster, answerCongressionalQuery(Foster))}$$

has an inconsistent obligation with

$$\mathrm{obligated(Foster, \neg answerCongressionalQuery(Foster))}$$

### 5.6 Psychological Commitment

Psychological commitment has been studied in Artificial Intelligence by Bratman, Cohen, Georgeff, Grosz, Harman, Huber, Hunsberger, Jennings, Kraus, Levesque, Nunes, Pollack, Sidner, Singh,etc.

Psychological commitmentis subject to certain pitfalls including the following:

- *omniscience of deductive consequence*: Typically psychological commitment has been based on psychological beliefs. However, an Agent cannot be expected to be psychologically committed to all the deductive consequences of their beliefs because of combinatorial intractability.
- *mentalism*: Psychological commitment has been widely criticized as being based on mentalism which makes it subject to great uncertainty because the current state of development in Artificial Intelligence. Such mentalism was the subject of great controversy in the 1991 AAAI Fall Symposium on Knowledge and Action at Social and Organizational Levels.

The notion of physical commitment as defined in this paper is not making the kind of psychological assumptions that are involved in psychologically based accounts of commitment [22], etc.

### 5.7 Electronic Institutions

[10] presented an analysis in terms of a normative framework of obligations, permissions, prohibitions, violations, and sanctions, which can be formalized in terms of physical commitment.

For example consider the commitment to be a *Fishmarket* in which buyers submit bids to an auctioneer in a Dutch auction to purchase round lots of fish. A proper *Fishmarket* provides that

- its participants have particular obligations, permissions, and prohibitions
- that certain violations may occur
- if violations occur, what sanctions are imposed

It is possible to implement an actual *Fishmarket* in the form of an electronic institution (e.g. as described in [21]) in which information technology plays an important role in the operations of obligations, permission, prohibitions, and sanctions. Once this has been done (e.g. in Blanes) we can look at the physical commitment that the fish market in Blanes operates as a proper *Fishmarket* at some particular time (e.g. 12 December 1997). In this regard, it would be possible to have every participant take part in a full audit on 13 December 1997 of what happened the previous day and then sign a contract that to the best of their knowledge all of the *Fishmarket* obligations, permissions, prohibitions, and violations had been obeyed on the previous day. However, although they are evidence, just by themselves, these contracts may not definitely settle the question as to whether a proper *Fishmarket* operated in Blanes on 12 December 1997. E.g., error or fraud (large or small) may still be a possibility. (See [2] for a flexible extension of electronic institutions to allow for a flexible enforcement of norms and manners.)

## 6 Speech Act Semantics

Speech Act Theory has been developed by philosophers and linguists to account for the use of language beyond simply stating propositions as in mathematical logic. Speech Act Theory encompasses *perlocutionary* and *illocutionary semantics.*

### 6.1 Limitations of Perlocutionary Semantics

The perlocutionary semantics of a speech act the effect, intended or not, achieved in an addressee by a speakers utterance, e.g., persuading, convincing, scaring, insultng, getting the addressee to desire something, etc.. However, perlocutionary semantics is limited in scope to mental state of the addressee. In terms of physics, the addressee is a dingable! In fact the speaker and addressee may be entangled and even privately interacting unbeknownst to an observer.

### 6.2 Limitations of Illocutionary Semantics

The illocutionary semantics of a speech act is the basic purpose of a speaker in making an utterance, *e.g., Assertive, Commissive, Declarative, or Expressive* as follows:

– *Assertive*: The speaker expresses that the state of affairs described by the propositional content of the utterance is actual.
– *Commissive*: The speaker expresses that they are committed to bring about the state of affairs described in the propositional content of the utterance.
– *Declarative*: The speaker expresses that they are bringing into existence the state of affairs described in the propositional content of the utterance.
– Directive: The speaker expresses that they are attempting to get someone to bring about the state of affairs described by the propositional content of the utterance.
– Expressive: The speaker expresses that they are communicating an attitude or emotion about the state of affairs described in the propositional content of the utterance.

Illocutionary semanticsis limited in scope to the psychological state of a speaker. However, it is unclear how to determine psychological state! Also commitments dont fall neatly into the pigeonholes specified by speech act theorists. Furthermore the speaker and addressee may be entangled.

### 6.3 Web Services

FIPA attempted to promote Agent Communication Languages based on Speech Act Theory. This pioneering effort ran into many difficulties including the problem of trying to pigeonhole communications into the FIPA prescribed illocutionary performative communicative acts whose semantics are expressed terms of psychological beliefs [7].

Subsequently attention has turned to Web Service standardization. However the current Web Services standards lack formal semantics.

## 7 Prospects and Future Work

On the 40th anniversary of the publication of Moore's Law, hardware development is furthering both local and nonlocal massive concurrency. Local concurrency is being enabled by new hardware for 64-bit many-core microprocessors, multi-chip modules, and high performance interconnect. Nonlocal concurrency is being enabled by new hardware for wired and wireless broadband packet switched communications. Both local and nonlocal storage capacities are growing exponentially. All of the above developments favor the Actor model.

The development of large software systems and the extreme dependence of our society on these systems have introduced new phenomena. These systems have pervasive inconsistencies among their documentation, implementations, and use cases. There is no prospect for eliminating these inconsistencies. Furthermore, there is no evident way to divide up the information into consistent microtheories. Organizations such as Microsoft, the US government, and IBM have tens of thousands of employees pouring over hundreds of millions of lines of documentation, code, and use cases attempting to cope. Also it would be fair to say that our society is becoming increasingly "committe" to these large software systems. Implications of this circumstance are on the agenda for future research.

Prospects for Agents are difficult to estimate. Currently Web Services do not assign any large role to Agents. On the other hand the semantics of commitment whose development is furthered in this paper are crucial to the future development of Web Services. So one issue before us is what science, technology and terminology will Web Services use for these concepts going forward. For our future Agent systems research, we will need to take the following measures:

- Make extensive use of monotonicity, commutativity, pluralism, skepticism, and provenance.
- Use (binary) XML to express commitments organizing them in viewpoints (theories, contexts) making use of inheritance and translation.
- Further develop semantics and pragmatics for processing expressions for commitments.
- Develop formal semantics for Web Services.
- Study how human individuals, organizations, and communities process expressions for commitments using psychology, sociology, and philosophy of science.
- Prepare for the semantic consequences of massive concurrency both local (many-cores) and nonlocal (Web Services).

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## Appendix: Discreteness of Each of the Arrival Orderings and Discreteness of the Activation Ordering Together Do Not Imply Discreteness of Combined Ordering Even if There Is No Change in Behavior

Clinger in [6] surprisingly proved that the Law of Finite Chains Between Events in the Combined Or-dering is independent of the discreteness of the arrival orderings and arrival ordering. The following result generalizes the result of Clinger because it shows that change in behavior is not required for the result to hold.

**Theorem 6.** *The Discreteness of the Combined Ordering is not implied by the individual discreteness of the Activation ordering and the Arrival orderings* ***even if there is no change in behavior****.*

It is sufficient to show that there is an Actor computation that satisfies the previously stated laws but violates the Law of Finite Chains Between Events in the Combined Ordering. Such a computation can be generated by $Initial.Start\lceil\rceil$ where [4]

```
Initial ≡
     receiver
 Start⌈ ⌉ →
    let initialGreeter = Greeter.Create⌈ ⌉
       then send InitialAgain⌈initialGreeter⌉
 Again⌈oldGreeter⌉ →
    let nextGreeter = Greeter.Create⌈ ⌉
```

[4] The program uses messages expressed in XML using the notation $<\texttt{name}>_{\texttt{tag}}\lceil<\texttt{element}>_1\cdots<\texttt{element}>_\texttt{n}\rceil$ for"$<$" $<\texttt{name}>_{\texttt{tag}}$ "$>$" $<\texttt{element}>_1\cdots<\texttt{element}>_\texttt{n}$ "$<$"/$<\texttt{name}>_{\texttt{tag}}$"$>$" For example, `PersonName⌈First⌈"Kurt"⌉Last⌈"Godel"⌉⌉⌉` prints as follows: `<PersonName><First>Kurt</First><Last>Godel</Last></PersonName>`

*then* {*send* `InitialAgain⌈nextGreeter⌉`
*also send* `nextGreeter SayHelloTo⌈oldGreeter⌉`}

The above program which defines the Actor Initial makes use of the following program for Greeter:

`Greeter` ≡ *receiver* `Request⌈Create⌈ ⌉customer⌉` →
*send* `customerReturned⌈` *serializer* `SayHelloBehavior()⌉`

`SayHelloBehavior()` ≡
*behavior*
`SayHelloTo⌈oldGreeter⌉` → { *send* `oldGreeterHello⌈ ⌉`
*also* `SayHelloBehavior()`}
`Hello⌈ ⌉` → `SayHelloBehavior()`

Consider a computation which begins when an actor *Initial* is sent a `Start⌈⌉` message causing it to take the following actions:

Send `Initial` the message $\mathtt{Again}\lceil\mathtt{Greeter}_1\rceil$. Thereafter the behavior of `Initial` is as follows:

> On receipt of an $\mathtt{Again}\lceil\mathtt{Greeter}_\mathtt{n}\rceil$ (which we will call the event $\mathtt{Again}_\mathtt{n}$) create a new actor $\mathtt{Greeter}_{\mathtt{n}+1}$ which is sent the message $\mathtt{SayHelloTo}\lceil\mathtt{Greeter}_\mathtt{n}\rceil$ and send *Initial* the message $\mathtt{Again}\lceil\mathtt{Greeter}_{\mathtt{n}+1}\rceil$

Obviously the computation of *Initial* sending itself `Again` messages never terminates. The behavior of each Actor $\mathtt{Greeter}_\mathtt{n}$ is as follows:

- When it receives a message $\mathtt{SayHelloTo}\lceil\mathtt{Greeter}_{\mathtt{n}-1}\rceil$ (which we will call the event $\mathtt{SayHelloTo}_\mathtt{n}$), it sends a `Hello⌈ ⌉` message to $\mathtt{Greeter}_{\mathtt{n}-1}$
- When it receives a `Hello⌈ ⌉` message (which we will call the event $\mathtt{Hello}_\mathtt{n}$), it does nothing.

Now it is possible that $\mathtt{Hello}_\mathtt{n} \rightarrow \mathtt{Greeter}_\mathtt{n} \rightarrow \mathtt{SayHelloTo}_\mathtt{n}$ every time and therefore $\forall \mathtt{nHello}_\mathtt{n} \rightarrow \mathtt{SayHelloTo}_\mathtt{n}$.

Also $\mathtt{Again}_\mathtt{n} - \approx\rightarrow \mathtt{Again}_{\mathtt{n}+1}$ every time and therefore $\forall \mathtt{nAgain}_\mathtt{n} \rightarrow \mathtt{Again}_{\mathtt{n}+1}$.

**All of the Laws for the Activation Ordering and Arrival Orderings Individually Are Satisfied.**

However, there are an infinite number of events in the combined ordering between $\mathtt{Again}_1$ and $\mathtt{SayHelloTo}_1$ as follows:

$$\mathtt{Again}_1 \rightarrow \cdots \rightarrow \mathtt{Again}_\mathtt{n} \rightarrow \cdots\infty\cdots \rightarrow \mathtt{Hello}_\mathtt{n}$$
$$\rightarrow \mathtt{SayHelloTo}_\mathtt{n} \rightarrow \cdots \rightarrow \mathtt{Hello}_1 \rightarrow \mathtt{SayHelloTo}_1$$