Analysing and Diagramming Complex Heterogeneous Activities

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Abstract
We increasingly live in heterogeneous ever-changing webs of activities where human actions are intertwined with events created by automatic machines. In order to make such webs understandable to its human participants, their structure should be represented by displays emphasizing their action aspect. The paper suggests thematic roles as a semantics for actions, argues that a selection of well-known diagramming techniques can be defined within this theory, and uses the theory to discuss new issues related to process control and mobile technology.

1 Purpose and overview

The topic of this paper is complex activities, i.e. purposeful activities comprising many interrelated actions, cooperating actors, and automatic systems. In Section 2, I present a semantics for analysing such activities and the way they change; Section 3 argues that a selection of already existing diagramming techniques can be interpreted by means of this semantics; and Section 4 describes modelling problems caused by inhomogeneous webs of activities performed by humans and machines, and discusses how they can be treated within the framework.

The basic motivating assumption in the following is that technology, ranging from administrative information technology to control technology of complex machinery, is related to actions in two ways:

1 As emphasised in Lind (1990, 1994) and Rasmussen, Pejtersen & Goodstein (1994), complex machinery cannot be understood without taking into account the goals, means and ends of the engineer. Although at some level, machines work according to purely physical forces, these forces have been harnessed by the engineer to perform purposeful actions. In this sense, machines can be said to be crystallised human actions and operations.
2 As emphasised by Goldkuhl & Ågerfalk (2002), Liu (2000), Bækgaard (2001), and many, many others, information systems are media for people to plan, execute, monitor, and evaluate business activities.

If this is true, then the displays offered to the operators of the machinery or the users of the information systems ought to represent the workings of the machinery in terms of the actions it crystallizes or mediates. This again makes it relevant to devise diagramming methods that displays actions in an illuminating and correct way. For example, in their recent study of air safety, Revilla & Sanchez-Alarcos 2003 emphasises the importance of knowing *how* the system works in opposition to understanding *what* it does – understanding the *logical* model in opposition to the *operational* model.

In addition to this, a more radical view claims that organizations, standards, and technology are increasingly becoming unstable entities that cannot be designed to last for a prolonged

period of time, but must be seen as emergent structures of organisational actions that are in constant flux (Truex, Baskerville & Klein (1999), Damsgaard & Truex (2000)). If this is true, then the demands for understanding technical systems in terms of business activities increase by an order of magnitude: the reason is that one has to understand what one changes, and if change of technological systems is motivated by new business processes, then the systems must be interpretable in terms of business processes.

The framework set up in the following belongs to the "emergence" paradigm, since it is based on simple local forces operating between actions.

2 The framework

This section establishes a framework for representing complex actions. From the introduction it follows that principle (A1) must be valid to some extent:

(A1) Social activities involving a multitude of actors should be interpretable to the involved actors.

The reason is, that if the actors cannot interpret the actions of other actors, they cannot figure out how to respond purposefully to them, therefore they will be unable to cooperate, and therefore the uniting purpose will be defeated (cf. Goldkuhl 2001: 9). For this reason, the basic unit cannot be an action pure and simple, but must be the pair <interpretation, action>. (A1) is a normative statement that is certainly not always true, but ought to be true in certain situations; among those are safety critical activities where failures may cause loss of life and valuables (for maritime strategies for enhancing understandability of actions, see Andersen 2000).

However, in order for us to observe interpretations, we must have some physical manifestation to work with, since mind-reading is not yet available as a technique. One such manifestation is the representations people use to communicate their interpretations. It can be language, but also includes gestures, facial expressions, and even ways staging of the actions themselves; if we use artefacts in our activities, they can also be used for representing our interpretations. For example, the driver signals his intention to turn by using the indicator. Therefore, the basic unit of analysis must be the unit <representation, interpretation, action>.

The next assumption is that

(A2) The three elements <representation, interpretation, action> form part of a many-to-many relation that is governed by systematic and motivated rules.

Thus, although one action can have several interpretations, and one interpretation can be expressed by several representations, the choices we make are systematic and motivated.

For example, the same sales transaction can be described as (Fillmore 1977)

(1) Ann sold the car to Bill for £1000
(2) Bill bought the car from Ann for £1000

(1) and (2) interpret the transaction differently, since (1) classifies Ann as the initiator of the activity while (2) assigns Bill to this role (the Initiator macro role is discussed in Section 3.3).

To increase the complexity, each of these different interpretations can be represented in more than one way. Besides (1) we have also (3) and (4) that maintain the same conceptual structure, but which distributes the focus of interest in a different way. In opposition to (2), (4) clearly indicates that the focus of interest is the car, not Ann or Bill.

(3) The car was sold to Bill by Ann for £1000
(4) It was the car Ann sold to Bill for £1000

The actors involved in the activity will typically prefer different types of interpretations that are partly predictable from their role in the activity (for empirical examples, see e.g. Holmqvist & Andersen 1991).

The choice of the ternary relation, <representation, interpretation, action>, implies the basic assumption that
(A3) All human activities are mediated.

The point is that there are no direct connections between the actions we do or perceive and their representation; we have to go through the mediating instance of interpretations. This is in accordance with Peircean semiotics that posits the Interpretant as the mediating instance, and with activity theory that inserts a Mediator (which can be a tool and a sign) between the Subject of an activity and its Object.

If interpretations are the central mediating element between representations and actions, it becomes important to elaborate a precise and empirically adequate definition of the concept. In the next sections I shall present the notion of *thematic roles* as an empirically motivated way of analysing interpretations.

2.1 Thematic Roles

Thematic roles denote relations between a process and its participants. The theory claims that

- there are a limited number of thematic roles (normally between ten and twenty),
- each process type can be characterised by requiring a small number of obligatory roles,
- there are important regularities in the way roles are expressed in sentences. Specifically, roles are systematically marked by case-inflexion, prepositions and/or word order.

According to the English linguist M. A. K. Halliday – and a good number of other linguists as well – the roles are divided into *participants* that are more or less obligatory for a particular process type, and *circumstances* that are more loosely associated to the process, and can occur with many types of processes. The rough rules relating interpretations to representations such as *Birds are flying in the air* are that the process is expressed by means of the verbal group (*are flying*), the participants by the nominal group (*birds*), and circumstances by adverbial groups or prepositional phrases (*in the sky*).

Halliday 1994 distinguishes between a dozen of process types, including

Process type	Participants	Examples
Material processes	Actor, Goal	*The lion* caught *the tourists*. *The mayor* dissolved *the combine*.
Mental processes	Senser, Phenomenon	*Mary* liked *the gift*. *She* saw *it coming*
Relational processes		
Intensive processes	Carrier + Attribute Identified + Identifier	*Your story* sounds *complete nonsense.* *Alice* is *the clever one*.
Circumstantial	Carrier + Attribute	*The ship* is in *Hamburg*
Possessive	Possessor + Possessed	*Peter* has a *piano*
Verbal processes	Sayer, Verbiage, Receiver, (Target)	Can *you* describe *your apartment* for *me*?

Table 2.1. Process types.

The list of circumstances includes: Extent (distance, duration), Location (place, time), Manner (means, quality, comparison), Cause (reason, purpose, behalf), Contingency (condition,

concession, default), Accompaniment (comitation, addition), Role (guise, product), Matter, Angle.

A more traditional list of participants and circumstances is given by Jurafsky & Martin (2000). Table 2.2, which I shall use in the following, is adapted from their list:

Agent	The volitional cause of an event: Can *we* berth her without a tug?
Experiencer	The sentient being that senses an event: Maybe *we* can see the 'Gudrun' from here.
Force/Cause	The non-volitional cause of an event: As *she* goes full speed at shallow water, then *she* creates a water wave
Theme	The participant most directly affected by an event: Can we berth *her* without a tug?
Material	The thing that changes identity in an event: Isn't that the only place where we get a copy *of those receipts?*
Result	The final identity of the material: We make *a three sixty* (maneuver)
Content	The proposition or content of a propositional event: I said to him *that as soon as you were finished steering, you would come down so that we could get it in*
Instrument	The tool used in an event: Can we berth her *without a tug*?
Beneficiary	The non-Agent that benefits from an event: I said to *him* that as soon as you were finished steering, you would come down so that we could get it in
Source	The start location of the Theme of a transfer event: I really thought he came *from Rotterdam*
Goal	The end location of the Theme of a transfer event: 'Gudrun' must sail before we can get *in*.
Purpose	The intention of the Agent of the event: Well, down to about 7.5 meters draught, you need that *in order to run properly with the top of the tunnel.*
Time	The time of the event: he will not sail *until two o'clock*.
Location	The place of the event: we are still lying *here* waiting
Manner	The manner in which the event is performed: Shall we start turning *slowly* now?

Table 2.2. A list of thematic roles. Authentic examples from the maritime domain.

In addition I shall use Halliday's relational roles, *Carrier* + *Attribute*, and *Possessor* + *Possessed.*

2.2 Discursive and enacting behaviour, glue and fillers

There is a difference between talking about cleaning the house and actually doing it. Talk does not remove dust, a vacuum cleaner does. For this reason we must distinguish between *discursive* and *enacting* behaviour. On the other hand, the two kinds of behaviours are always intermingled and mutually presuppose one another. For example, first the captain gives order to turn the wheel 5 degrees starboard, then the helmsman turns the wheel while observing the rudder angle indicator, and when the indicator reaches 5 degrees, the helmsman reports back. The task would not have been done, had the order not been issued; and the report will only be given when the task is finished. Furthermore, enacting behaviour can often functionally replace discursive behaviour. When the library borrower returns his books, he may not need to *say* that he considers his commitments fulfilled; it suffices that he places the books on the reception counter.

Thus, although discursive and enacting behaviour are clearly different, they are more like endpoints of a continuous scale, with many in-between forms, than absolute opposites. We can express these facts by saying that discursive behaviour focuses on the *representation* ↔ *interpretation* interaction, while the focus of enacting behaviour in on the *interpretation*↔*action* interaction. In the former case, the purpose is to figure out the interpretation of a certain representation or finding the best representation for the interpretation you have in mind. In the latter case, you use the interpretation to guide your own actions, or you try to make sense of actions performed by another person – or yourself, for that matter!

From this point of view, we need to consider the detailed transformations that relate interpretations to discursive (representations) and enacting (action) behaviour.

Interpretation ↔ Discursive behaviour. There is a body of theory describing the way interpretations in terms of thematic roles can be realized as sentences (Valin & LaPolla 1997). I shall not go further into this, since it is a speciality for linguistics.

Interpretation ↔ Enacting behaviour. In this case, there is no received body of theory we can rely on, and since enacting behaviour is the main topic of this paper, I shall focus on this relationship. In particular, I am looking for (1) rules relating interpretations to actions, (2) introduction of new categories motivated by the way we act, and (3) introduction of new processes and transformations motivated in the same way.

(1) Rules of interpretation. A very common transformation relating actions to interpretations is the following: if an Agent is influencing some equipment or staff, and this equipment or staff is influencing some work object, then the Agent can interpret himself as directly influencing the work object. Examples are numerous: although the captain can only directly influence the machine telegraph which again influences the main engine which again influences the speed of the ship, he can use a short-cut where he himself influences the ship: *We can give her a kick a head (by means of the machine telegraph)*. This interpretation signals that he is in control of the ship, and can be used to guide his utterances. But in its literal interpretation, it is not much good for actually changing the speed of the ship. In order to do this properly, the captain must be conscious of larger parts of the causal chain. For example, too much acceleration of the engine will produce an increase of propeller rotation that only produces foam, not speed.

The transformation the captain uses can be captured by a very simple and general rule saying that if an Agent influences a Theme which acts as a Cause for influencing another Theme, then the Agent can see himself as directly influencing the latter Theme:

(T1) $\text{Agent}_1\ \text{Theme}_2 + \text{Cause}_2\ \text{Theme}_3 \leftrightarrow \text{Agent}_1\ \text{Theme}_3$

(2) Action categories. In everyday speech, we do not distinguish very clearly between the roles of Agent and Cause: both normally become the grammatical subject of the sentence. Thus, the officer can say:

(1) … then *it* sails by itself
(2) *You* sail with the rudder delimiter all down at ten degrees, right?

where *it* refers to the automatic voyage management system of ship. However, in the operating procedures, the Cause (the automatic machinery) and the Agent (the human crew) are very sharply distinguished: the more complex navigation becomes, the more manual it is required to be. Automatic steering is forbidden in trafficked areas. Similarly, causal reasoning used in error diagnosis requires us to distinguish between active and passive Causes (Petersen 2000), a distinction that is absent in language. Consider the furnace plant in Fig. 2.1.

Suppose that too much metal is produced in Fig. 2.1. Since the outlet is passive - a pipe that uses gravity to move the molten metal - the error cannot be located here. But since the conveyor belt is active and *itself* moves ore into the furnace, a surplus of metal may be due to the conveyor belt running too fast. On the other hand, if the ore were removed by active means, for example by some kind of a suction system, then this system could be the culprit (Petersen 2000). Thus, although we say that *the conveyor belt moves ore into the furnace*, and that *the*

pipe moves the molten metal out again and thus treat belt and pipe similarly in discursive behaviour, we must distinguish when we are reasoning about the actions.

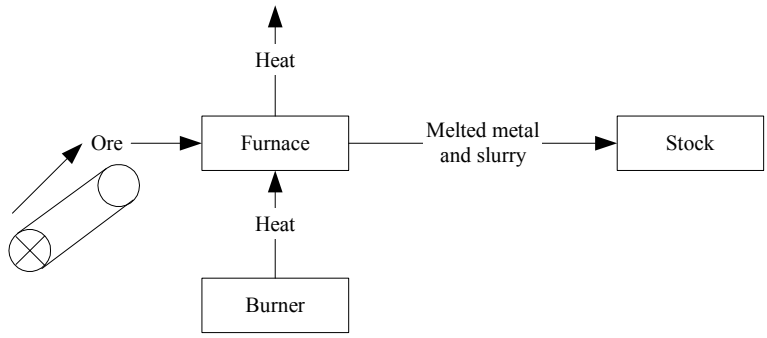


Fig. 2.1. The furnace plant example.

(3) Action transformations. For practical purposes, actions are often grouped in special ways and new categories related to this grouping are introduced. One such category is the notion of a *position*. A position can be defined as a macro role whose filler is required and entitled to fill specified thematic roles in a delimited set of actions. For example, when a librarian is employed, she is required and allowed to be the Agent of cataloguing, lending, reserving, and recalling books, while the borrower, properly registered as such, is the Agent of the actions of lending, returning and paying fines, and the Beneficiary of the librarian's reserving actions. Positions are used in Section 3.3.

We also often group actions according to their Location, in particular if they require special equipment. Thus all actions requiring the use of X-rays are collected in the X-ray department of a hospital, while all operations are done in the operating theatre. Groupings according to Location roles are used in Section 4.3.

Finally, if we interpret equipment in general as fillers of human actions *(I drove to the airport by car),* and automatic equipment, in particular, as fillers of Causes *(The car accelerates fast)*, we can describe aspects of the architecture of automatic systems as transformations of role-structures. For example, some automatic systems are built in levels, so that Cause of the lower level acts as the Instrument of actions performed by a higher level Cause. This is captured in transformation T2:

(T2) Cause Theme Instrument$_1$ $\rightarrow$ Cause$_1$ Theme Instrument

In maritime automation, for example, the Voyage management system that keeps the ship on the track uses the autopilot as an Instrument. At the level below, however, the autopilot is the Cause of the process of maintaining the course. This is discussed in Section 4.2.

Finally, a very frequent transformation in most work is focus shift (Bødker 1991). It consists in moving the filler of a role like Instrument or Location in one action to the role of Theme in another action, as described in T3.

(T3) Agent$_1$ Theme Instrument$_2$ $\leftrightarrow$ Agent$_1$ Theme$_2$ Instrument

Thus, when the captain is sailing, the autopilot is his Instrument and his attention is focused on following the track. But in case of course changes, his attention may shift to the autopilot which then becomes his focus of interest. And if the course knob is faulty, this instrument for setting the autopilot may become his focus of attention. Thus (T3) can be applied recursively:

(1) The captain follows the track (Theme) by means of the autopilot (Instrument) → The captain sets the autopilot (Theme) by means of the course knob (Instrument) → The captain turns the knob (Theme).

In the preceding we have just assumed that people and objects act as participants in actions – they are fillers of certain roles. However, we need to express additional phenomena:

- The same filler can play different roles in different actions: when I clean the house the living room is the Theme of my cleaning actions, whereas it is the Location of watching television.
- A filler can begin or cease to play a certain role: when the librarian is hired, her rights to fill the Agent role of lending books begins, and they cease when she is fired (Bækgaard 2001). I distinguish between the following changes of glue: * = *produce*, † = *destroy*, / = *maintain*, \ = *prevent* (Lind 1994). Hiring a librarian thus produces her rights, while firing her destroys them. Taking courses maintains her ability to function as a librarian, and prevents firing.
- A filler can be more or less suitable for playing a certain role: my lawn mower is well suited as the Instrument for mowing the lawn if the grass is not too high; otherwise I have to replace it by a scythe.
- In addition, humans may have obligations or desires to fill a role, or they may be prohibited from it or dislike it. Where humans are concerned, the sheer ability to do something is not enough to predict the execution of an activity; we need to add *obligation, desire* and *intention*.
- Finally, filling a certain role in one action may change the filler's ability, obligation, desire, or intention to do so in another action: when the borrower has participated as Theme in the registration event, he acquires the right to become the Agent of a borrowing event, and the Beneficiary of a reservation event.

In order to accommodate these needs, we introduce the notion of a bond – a "glue" – that binds a filler to a role. The bond has at least four dimensions: *ability* describes the degree to which the filler's physical and/or psychic properties allow it to play a certain role – *I can do it*; *ethics* describes the social obligations or prohibitions regulating the role – *I ought to do it; emotions* accounts for the filler's desire, reluctance, or fear of assuming the role in question – *I'd like to do it;* and *intentions*, the filler's plan for the future – *I will do it.*

3 Reinterpreting existing diagrams

Thematic roles have been used for constructing diagrams for technical purposes. The best known example is the conceptual graph notation developed by John Sowa (Sowa 2000) but there are other examples (Parunak 1995). In this section I argued that a number of other diagram types can be defined by means of thematic roles.

3.1 Dataflows

The first example is the well-known data flow diagrams.

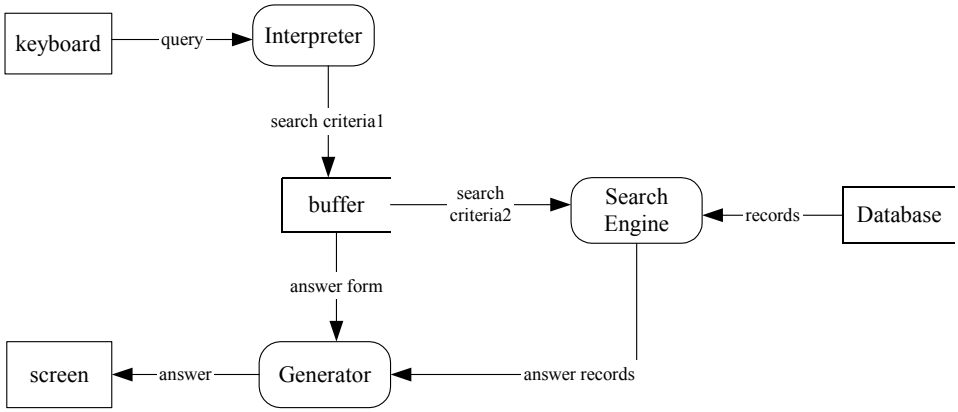


Fig. 3.1. Dataflow diagram.

Out of the many kinds of statements that can be made about a data base system, the flow diagram picks out only those that contain the Cause, Theme, Result, Material, Source and Goal participants and the verbs *produce*, *get*, and *put*. Examples:

(1) *The Interpreter* produces *search criteria* from *queries*. (Cause, Result, Material)
(2) *It* puts *them* put into a *buffer*. (Cause, Theme, Goal)
(3) *The Search Engine* gets the *search criteria* from *the buffer.* (Cause, Theme, Source)
(4) *It* produces *answer records* from *the criteria and data base records.* (Cause, Result, Material).
(5) T*he Generator* produces *an answer* from *the answer form and the answer records.* (Cause, Result, Material)

Fig. 3.1 codes this in the following way: fillers like *Interpreter, Search Engine*, etc., are represented as text labels attached to graphical boxes and arrows, except verbs that are not represented. The *role* relations are represented graphically: Causes are presented as rounded rectangles, Material as ingoing arrows to Causes, Results as outgoing arrows, and Sources and Goals as rectangles with a missing side.

3.2 MFM models

A more sophisticated example is the Multi-level Flow Models defined in Lind 1990 and 1994. MFM-models are intended to (1) describe flows of energy and matter in complex plants in a physically correct way, and (2) emphasize that the plant is designed and cannot be understood without understanding the engineer's intentions and purposes. In the following we shall not consider the Purpose-role in (2) but concentrate on (1). It is built on the following six functions:

Function	Definition	Icon
Transport	Something that *transports* substance	
Storage	Something that *stores* substance	
Balance	Something that *distributes* substance.	
Barrier	Something that *blocks* transport of substance	
Source	Something that *provides* substance	
Sink	Something that *consumes* substance	

Table 3.1. Definition of functions.

The six basic flow-functions can be summarized in two thematic role structures:

(1) *Cause* transports *Theme* from *Source* to *Goal*
(2) *Cause* stores/distributes/blocks/provides/consumes *Theme*

Fig. 3.2 diagrams the plant in Fig. 2.1. The sentences used are the following (cf. Andersen 2002a).

A Repository provides ore.
A conveyor belt transports the ore from the repository to a furnace.
The furnace distributes the ore.
A pipe transports the ore from the furnace to a stock.
The stock consumes the ore.
A motor provides movement.
The conveyor belt transports the movement from the motor to the ore.
The ore consumes the movement.
A burner provides heat.
Air transports the heat from the burner to the furnace.
The furnace stores the heat.
Air transports the heat from the furnace to a furnace wall.
Air transports the heat from the furnace to the ore.
The furnace wall stores the heat.
The ore stores the heat.
An pipe transports the heat from the furnace wall to an environment.
An pipe transports the heat from the ore to the environment.
The environment consumes the heat.

Text 3.1. Description of furnace plant.

The Cause fillers, such as *repository, furnace, burner,* etc, are represented by icons that depend upon the verb of the sentences in which they occur (cf. Table 3.1); their line type depends upon the Theme in the sentence, so if the Theme denotes a mass (*ore*) the icons have full lines, whereas they have dashed lines if the Theme denote energy (*heat, movement*).

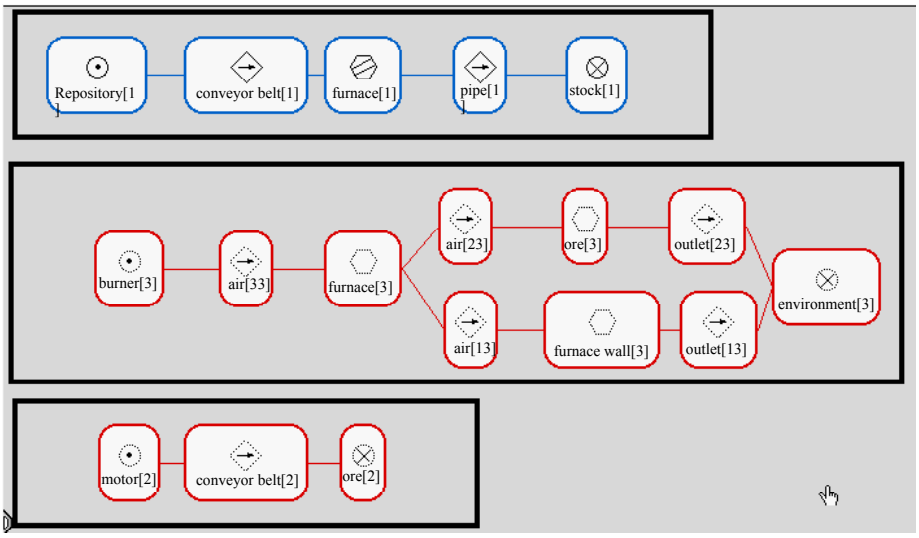


Fig. 3.2. Diagram, parts of MFM-Model

From the text it appears that many roles share fillers. For example, the *repository* is the Cause of *provides* but the Source of *transports* (A *repository* provides ore. A conveyor belt transports the ore from the *repository* to a furnace). We want to emphasise these shared fillers, and therefore design the following coding: If the Cause of one event is the Source or Goal of another event, the Cause-icons of the events are connected by a line. Thus, the Repository, Conveyor belt, and the Furnace icons are connected because the repository provides ore, the

conveyor belt transports the ore from the repository to the furnace, and the furnace distributes the ore.

As demonstrated by the prototype described in Andersen 2002a, it is quite easy to automatically convert an internal representation based on thematic roles into textual descriptions like Text 3.1 and/or diagrams like Fig. 3.2.

3.3 DEMO: exploiting positions.

In section 2.2 I mentioned the notion of a position as a macro role whose filler can fill certain roles in a set of actions. This notion is exploited by Bækgaard 2001 and by the DEMO notation described in Dietz 2003. Consider the following text:

> A customer requests a baker to deliver a loaf. The baker promises to deliver the loaf or he declines it. If he declines, the customer quits the interaction – leaves the shop. If the baker promises, he decides to sell the requested loaf to the customer. Next, the baker states that the loaf has been delivered, e.g. by saying *there you are.* If the customer responds to it by accepting the loaf, the process reaches the successful terminal state. Adapted from Dietz 2003: 6

The following verbs occur: *request, promise, decline, quit, deliver, sell, state, accept.* Dietz defines two positions, the *Initiator* and the *Executor*, on the basis of who is responsible for what, i.e. who is the Agent of which actions:

The Initiator is the Agent of:

- Requesting to the Executor that he executes some action
- Quitting the interaction if the Executor denies the request.
- Rejecting the outcome of Executor's execution of the action.
- Accepting the outcome of Executor's execution of the action

The Executor is the Agent of:

- Refusing the Initiator the request
- Promising the Initiator to do something
- Stating to the Initiator that the action is executed
- Stopping the interaction

The diagramming technique includes the following simple rules (there are actually more, as can be seen from Fig. 3.3):

1. Make a box for the positions of Initiator and Executor.
2. Type the verbs of which they are Agents inside their boxes
3. Connect actions that are contiguous in time by an arrow leading from the earlier to the later action.

In addition, the actions are divided into two classes, production acts (*deliver, sell*) and coordination acts (*request, promise, decline, quit, state, accept*). The former aims at fulfilling the mission of the organization, while the latter aims at handling the commitments necessary to accomplish production acts. Coordination acts are highlighted since they are colored white and labeled while production acts are gray and unlabeled. Thus, coordination is emphasized at the expense of production. With a few more coding conventions the result is as shown in Fig. 3.3.

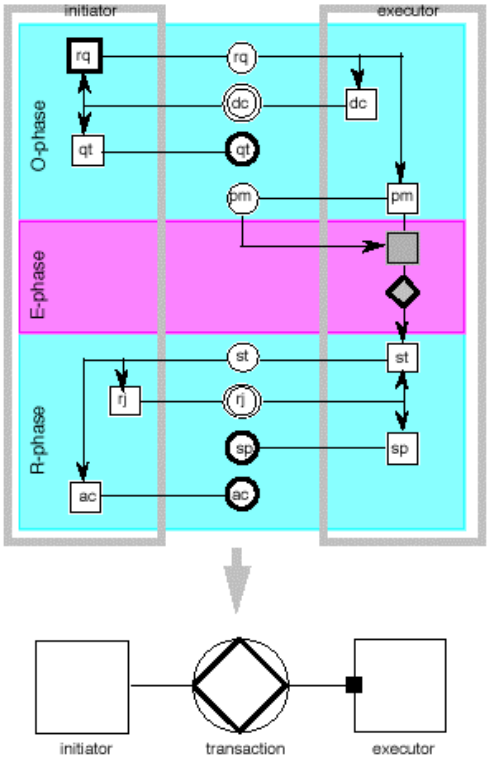


Fig. 3.3. The standard pattern of a transaction. From Dietz 2003. Rq = request, dc = decline, etc.

4 Webs of humans and machines

I have now shown that some well-known diagramming techniques can be defined by a selection of a few verbs plus a small set of thematic roles. In this section I shall address modeling issues raised by the following type of situations: (1) communicative and material actions are intertwined and influence one another – people talk and manipulate objects intermittently: *how are communicative and material actions related?* (2) In addition the same action is sometimes done by a machine, sometimes by a human: *how do we analyze these changes of agency?* (3) Finally, humans and machines move through space and their location influence what they do, what machines display, and how machines are used: *how can we represent the relation between actions, information and space?* This is the normal situation in maritime work (Andersen 2000), but if the notion of pervasive context sensitive computing is realized, it will also be the way we generally conduct our lives.

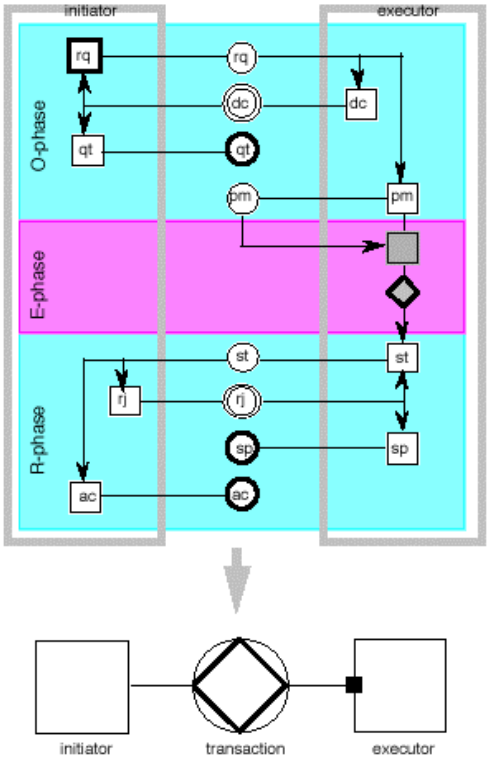
4.1 Material and communicative actions

In this section I show how the framework can be used to represent webs of actions, some of which are material actions aiming at changing dead matter, while others are communicative actions aiming at changing the beliefs or commitments of people.

Since we are interested in webs of actions, not the individual action, we represent the individual action as a textual table as shown in Fig. 4.1.

Agent	Process	Theme	Instrument
I	mow	lawn	Lawn mower

Fig. 4.1. Representation of single action



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I	mow	lawn	Lawn mower

Fig. 4.1. Representation of single action

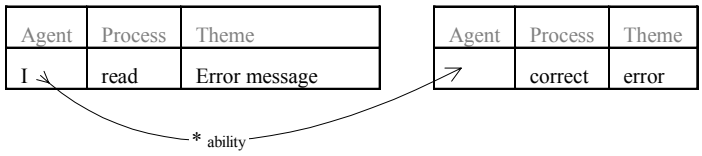


Fig. 4.5. Actability.

4.2 Agency changes: Agents and Causes

Webs of actions, where the agency of humans and non-humans changes, is described by having two versions of the same action: one with an Agent and one with a Cause role. As mentioned in Section 2.2, discursive praxis tends use the same grammatical category about mechanical Causes and human Agents, but in many cases, the two roles are clearly distinguished in action. There is good reason for distinguishing, for although the general logic of the two actions may be the same, their manner of performance can be very different.

Maritime technology is designed according to the following principle which in itself invites systematic shifts between Agents and Causes:

> First and foremost it must be required that every process that is crucial for the safe operation of the ship must be executable, even if the integrated system does not work. Therefore, it is always possible to control the most important engine and navigation elements manually – 'in the old-fashioned way' – independently of the state of the integrated system. *Lem & Nordseth 1996: 26.*

This means that a system component – the VMS, the Autopilot, or the rudder servo system – systematically plays two roles: as an Instrument of a super ordinate activity and as the Cause of a subordinate activity. The Autopilot is an Instrument for either officer (Agent) or the VMS system (Cause) to follow the track, but is also the Cause of setting and maintaining the course of the ship (cf. transformation T2 from Section 2.2).

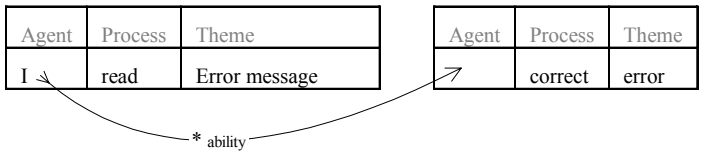
Therefore, the most important actions are designed to execute in two modes: automatic mode where the superordinate automation is the Cause of the subordinate action, and manual mode where the action has an Agent: sometimes the officer controls the autopilot, sometimes it is the VMS system that does it.

We can capture these two regularities in two simple transformational rules:

(T2) Cause Theme $\text{Instrument}_1 \rightarrow \text{Cause}_1$ Theme Instrument
(T4) Cause Theme_1 $\text{Instrument}_2 \rightarrow$ Agent Theme_1 Instrument_2

(T2) from Section 2.2 says that if there is a process using an Instrument then, at the level below, the Instrument functions as a Cause. (T4) says that if there is a process involving a Cause there will also be a process involving an Agent, i.e. all automatic processes can be done manually.

Fig. 4.6 shows how automatic machinery can be described in terms of thematic roles. One makes a description of the actions that comprise an activity, and describes the machinery as fillers of roles in the actions. Automation is thus described via its role in human activities.



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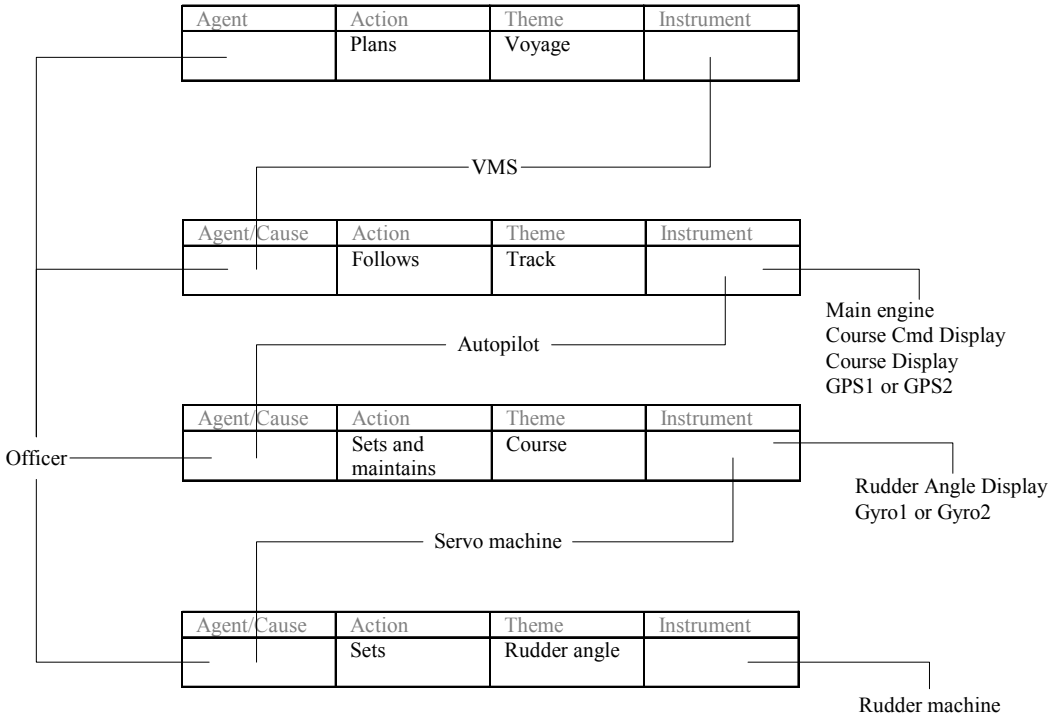

Fig. 4.6. The steering activity on a ship

The shared fillers define a means-end hierarchy (cf. Rasmussen, Pejtersen, & Goodstein 1994): the servo machine is a means for setting and maintaining the course, and the autopilot is a means for following the track.

4.3 Mobile technology: Maps

The last example is mobile context sensitive technology (which, by the way, has been in use in the transport sector for a long time!). The idea in mobile context sensitive computing is that the physical environment co-determines which information is presented to the user. This means that we are particularly interested in the Location and Time roles and want to highlight locations by graphical means. This has been done for thousands of years in the shape of maps, but mobile technology and context sensitive computing has re-actualized this.

A glance at a map reveals that maps are not only a projection of coordinates on a two-dimensional surface. Most maps have symbolic signatures indicating roads, railroads, ferry routes, hotels, camping sites, post offices, etc. These signatures indicate the *actions* that are possible at the particular location: you can go from city A to city B by train; you can eat and sleep here; you can put up your tent here, etc.

Consider now the case of designing context sensitive local services for an airport. For example, the advertisements of the shops in the departure hall should not be accessible from the entrance hall, since you cannot buy anything here, and neither should the instructions for reaching a certain gate. However, information about delays would be relevant in the entrance hall, and the status of the gate (not determined yet, boarding, closed) may be useful for late passengers.

The point of departure is a description of coordinates and actions like Text 4.1.

The entrance hall is located at $<x_1,y_1,z_1,w_1>$

The departure hall is located at <x_2,y_2,z_2,w_2>
The passport control is located between the entrance hall and the departure hall
The service counter is located in the departure hall
The liquor store is located in the departure hall
….
The passenger checks in at the counter *in the entrance hall*
The passenger shows ticket and passport *at the passport control*
The passenger negotiates a new flight *at the service counter*
The passenger buys whiskey *in the liquor store*
The passenger walks *from the departure hall to the gate*
The passenger enters the plane *at the gate.*

Text 4.1. Locations and events in an airport

The diagram in Fig. 4.7 is constructed from Text 4.1 according to the following simple coding conventions: (1) code all fillers of Location roles by means of spatial coordinates of the fillers. (2) code the remaining part of the action as text boxes and place it on the diagram in the vicinity of the coding of its Location filler. (3) Connect the two by a line.

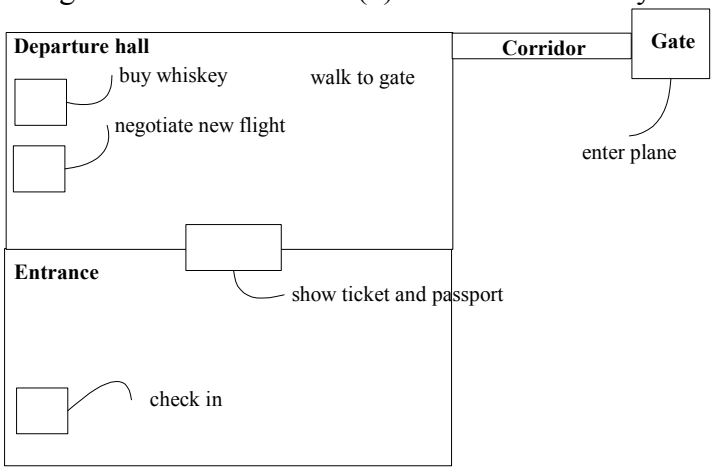

Fig. 4.7. Map decorated by actions.

Now that we know where (and when) the action is to take place, we can make good guesses about the time and location for sending information to the traveller's PDA that enables him to perform the action. For example, information about the route from the departure hall to the gate should be accessible in the departure hall.

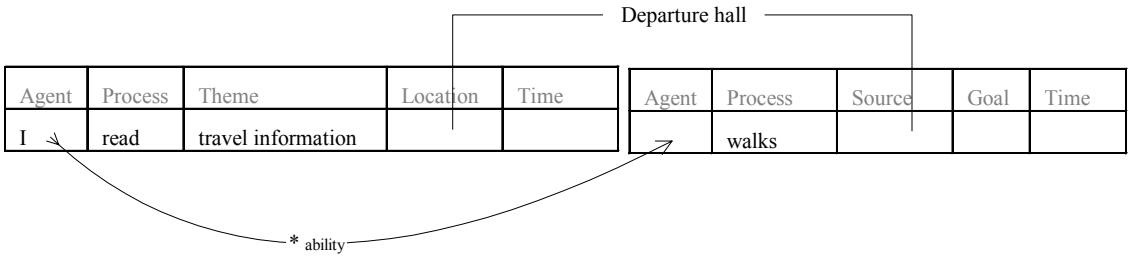

Fig. 4.8. Actability constraints on information about the route to the gate .

Fig. 4.8 describes the actability requirements of the airport information in the same way as Fig. 4.5: participation in a communicative action (here: reading) enables the passenger to participate in a business action (here: walking to the gate); in addition, it places restrictions on their fillers: the Location of the communicative action and the Source of the business action must be the same. I think this captures the essentials of mobile context sensitive computing: we create constraints on the Location (and/or Time) fillers of two actions A and B,

where A is a communication that changes the ability, obligation, etc. of A's Agent or Beneficiary to function as the Agent of B.

5 Summary

In this paper I have presented the theory of thematic roles and argued that the semantics of some standard diagrams can be formulated within the theory. In addition, I have used it for analyzing complex dynamic activities where humans, machines and space interact,

Acknowledgements

Thanks to the reviewers of this paper. They saved me from publishing a version that was by far more incoherent than the present version.

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