

# Context, Situations, and Design Agents<sup>\*</sup>

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## Abstract

The terms “context” and “situation” are often used interchangeably or to denote a variety of concepts. This paper aims to show that these are two different but related concepts and it reifies their difference within the framework of design agents. The external world of an agent is described as the aggregation of all entities that the agent could possibly sense or effect, where context is from its external world that an agent interacts with and is aware of. The interpreted world of an agent is described in terms of the experiences of that agent, where situations are processes that direct how interactive experiences proceed. Situations determine what part of the external world are in the current context, and situations influence interaction and so influence what and how common ground is acquired.

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## 1 Introduction

The terms “context” and “situation” are often used interchangeably, in some places are used to mean different things, and elsewhere are used with inverted meanings [1; 2; 3; 4; 5]. This paper aims to show that there are two different but related concepts being described and reifies their difference within the framework of design agents. In this paper, designers are considered to be situated agents. We develop some of the ideas from design examples, so the

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paper commences with some background to the generation and use of sketching and drawings in designing. A designer's sketches may contain visual signifiers, non-visual signifiers, and marks not intended to signify anything. Sketching activities are part of the dialogue between the designer and the drawing; they are part of a dialogue even if nobody else is present as the designer sketches. Sketches like this are often part of a sequence and are part of the processes of conceptual designing and communicating. There are sequences of sketching actions within one sketch and there are sequences of past sketches that the designer may or may not refer back to. The following is the architect and engineer Santiago Calatrava describing how he designs:

“To start with you see the thing in your mind and it doesn't exist on paper and then you start making simple sketches and organizing things and then you start doing layer after layer ... it is very much a dialogue” [6].

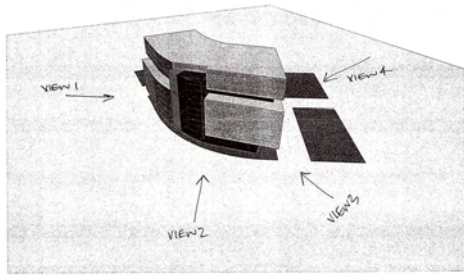
In a collaborative designing session such sketches constitute a conversation (indirect communication) along with any concurrent verbal communication (direct communication). Shapes in such sketches need not depict two/three dimensional forms or textual/other signifiers, and they need not be associated with concepts in the concurrent verbal communication.

“In many cases their drawings contributed relatively little to the meaning simultaneously conveyed verbally, and in most cases the drawing made almost no sense at all when viewed out of the context of the conversation” [6].

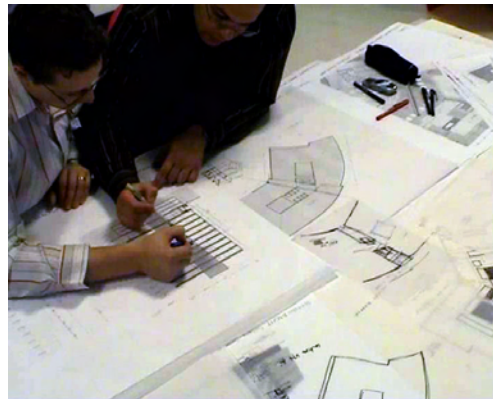
Designers are capable of seeing the world differently than the way it was initially intended. Research evidence suggests that designers “get inspiration and ideas from their drawings that they did not imagine in advance” [7]. For clarity we shall use the words “sketch” and “drawing” as follows. Some of the plans, sections and external views used in the Figure 1 session were drafted and then printed via a CAD package; Figure 1(a) is an example. We call images such as these “drawings”. Images produced by hand with pens and pencils on paper we call sketches regardless of whether they are conceptual and ambiguous, or detailed and clear; Figures 1(c) and 1(d) are examples.

The images in Figure 1 are from a collaborative design session. Figures 1(a) to 1(d) may be part of the conceptual design of a building. Maybe they are, but why is it of a building at all? Maybe Figure 1(c) really is no more than a sequence of marks or a loose aggregation of generic, imprecisely rendered shapes? One answer - the one that we focus on here - is that the designer acts as a situated agent. Situated agents use processes called situation processes to produce situations that change how the agent interprets the world. They are constructions of agents that give meaning to its interactions. A designer sketching Figure 1(c) will already have concepts constructed of the desired

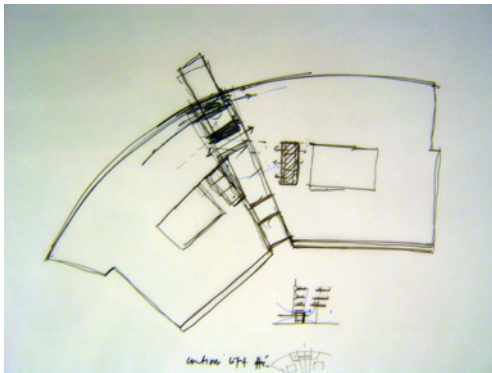
artefact, leading to a situation in which the sketch is interpreted as a building.



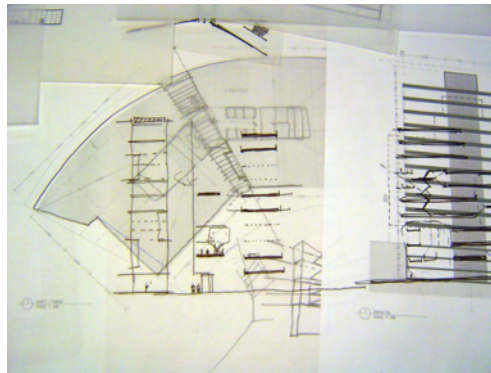
(a) Proposed building massing



(b) Discussing a section through the atrium



(c) Sketch of a floor plan



(d) Sketches of a section

Fig. 1. Images from [8] of a collaborative design session

This is not the simple notion of “situated” as synonym for “embodied”, although situated agents certainly are embodied in an environment. It is also not “situated” as synonym for “improvised” or for Brooks’ “reading of situated as nonrepresentational” [9]. It is of situated as an embodied agent whose situation processes direct how its interactive experiences proceed. To avoid confusion we use the phrase “situation process”, denoted by  $\mathfrak{s}_i$  for agent  $\mathfrak{a}_i$ , when referring to such a process. We use “the situation” and “situated” when referring to the result of situation processes on experiences.

Interpreting Figures 1(c) and 1(d) involves more than simple recognition that an aggregation of shapes is a representation of a building. The interpretation constructed depends on the intentions and past experiences of the designer.

“A building may be viewed as a set of activities that take place in it; as a set of spaces; as sculptural form; as an environment modifier or shelter provider; as a set of force resisting elements; as a configuration of physical elements; etc. A building is all of these, and more. A model of an object is

a representation of that object resulting from a particular view taken. For each different view of a building there will be a corresponding model.” [10].

If the designer is an architect, the sketched walls and floors will be interpreted as delimiting spaces that, in turn, satisfy spatial and environmental functions. If the designer is a structural engineer the sketched walls and floors will be interpreted as elements for bearing and resisting forces and moments. If the designer is an electrical engineer, the sketched walls and floors may only be cable routes. Looking at an external representation of a design - perhaps a conceptual sketch, a detailed CAD model, or a 3D virtual or physical mock-up - what the agents takes note of and how they interpret it will depend on their current situations.

Agents must be embedded in an environment and that environment will be an aggregation of entities. Some of those entities may be other agents, others may be things like pencils and paper. What we call the context for an agent are those entities outside of the agent that it is aware of its interactions with. At the location and time at which the Figure 1(c) sketch was made there was a context for the sketching agent. That context was part of the environment at that time. But our agents are situated, so they interpret that context according to the situation as they understand it. Context is not something in the “mind” of a designer but is part of the environment at the time and location that they are embodied. Contexts are characteristic of a system of interacting agents and things. This is like the patterns in the turbulent flow in Figure 2. These patterns are emergent or supervenient on the structure and behaviour of the river bed, the river bank, obstacles in the river, the wind, and the water. They may arise from interactions between non-agent things, between agents, between agents and things, and between subsystems in an agent.



Fig. 2. “Upon those who step into the same rivers different and ever different waters flow down”, Heraclitus (510-480 BC, translation from [11])

Moving from a single design agent to multiple collaborating agents, a set of designers collaborating will all be embodied in the same environment. Each

will have their own situation and so their own interpretation of what is the context. Some part of the environment must be in the context of each agent, though, or they could not communicate. If the collaborators are an architect called Mungo and a structural engineer called Boris, that part of the context that Mungo and Boris share is what enables communication. If Boris and Mungo are in the same physical and temporal location they can talk while one sketches and the other looks. The context of the collaboration in this case emerges from interactions between them, from what is currently in the sketch, from the sequence of sketching actions until now, and from other recent sketches and drawings that led to the currently attended one. It also emerges from that coffee that Mungo did not get this morning, from Boris noticing that the sun shining through that dirty window makes a nice pattern, from ...; that is, from influences of other entities on the agents. But it is the situation for Boris that drives what the context looks like for Boris. What counts as the context for each agent differs as consequence of the current situation.

If Boris and Mungo are in different physical or temporal locations, they need a medium that provides an overlap of their contexts or they cannot communicate: Morse code via a telegraph line, email via the Internet, a virtual world, whatever. More than just some overlapping context is required, though. Common ground is needed for each to usefully interpret the words spoken or shapes sketched. This is especially apparent when the designers are from different design domains.

Our notion of context is not the usual AI one introduced by McCarthy [1]. He defined a relation  $ist(c, p)$  asserting that a proposition  $p$  is true in context  $c$ , where the  $c$  is an abstract, first-class mathematical entity in the style of a fluent. The “attitude” taken is a “computer science or engineering one”:

“it seems unlikely that this study will result in a unique conclusion about *what context is*” [1, emphasis is McCarthy’s].

What  $ist$  provides is a mechanism for reaching a particular mathematical goal. Such a useful mechanism needs a name so it was called “context”, and it is undoubtedly useful. It seems to us, however, that calling such mathematical entities “context” provides much less than common sense descriptions of context would indicate. We don’t find this to be very satisfying, partly because not saying what something is risks formalising the wrong thing and partly because we believe that this approach misses something important.

“It is sort of commonplace to say that any representation is context dependent. By this, it is generally meant that the content of a representation cannot be established by simply composing the content of its parts” [4].

Benerecetti is correct - just saying that a representation is context dependent probably doesn’t say much by itself.

“situated actions are always, and irremediably, contingent on specific, unfolding circumstances that are themselves substantially constituted through those same actions” [9].

We agree with this sentiment but we feel uneasy that understanding the “unfolding circumstances” in the agent gets entangled with understanding the “unfolding circumstances” in the environment. They really are different kinds of phenomena. In this paper we try to disentangle context from situations and describe how these different but connected notions relate. We do this through a view of design agency that sits on three pedestals: that agents are interactive, that they are situated, and that their memories are constructive. We describe how both context and common ground follow from those, and how common ground comes from situations and not from context. We attached the labels “situation” and “context” to these phenomena as we view them, recognising that some readers hold differing views of what these labels mean. To those readers we ask for temporary acceptance of our definitions, as we believe there to be notions here deserving of consideration and differentiation regardless of the particular labels chosen for them.

## 2 Context

An environment  $\xi$  is an aggregation of entities  $\mathbf{o}_1, \mathbf{o}_2 \dots \mathbf{o}_N$  that perturb the processes of each other, where  $N$  is the number of entities in  $\xi$ . An aggregate is a collection of entities held together only loosely, whereas a system is an aggregate where the components interact [12]. The environment is that aggregate that is contained in no other. A conceptual aggregate is simply a set, whereas with a system the “whole is greater than the sum of its parts”. Entities can be things or constructs. Things are entities denoted by  $\mathbf{t}_1, \mathbf{t}_2, \dots \mathbf{t}_N$ , where  $N$  is the number of things. There are agents denoted by  $\mathbf{a}_1, \mathbf{a}_2 \dots \mathbf{a}_N$ , where  $N$  is the number of agents. An agent  $\mathbf{a}_i$  is composed of an agent-thing  $\mathbf{t}_i$  and some number of constructs  $\widehat{\mathbf{c}}_i = \mathbf{c}_i^1, \mathbf{c}_i^2 \dots \mathbf{c}_i^N$ , where  $N$  is the number of constructs of  $\mathbf{a}_i$ .

That part of the environment that is not agent  $\mathbf{a}_i$  is  $\xi - \mathbf{a}_i = \xi - (+\{\mathbf{c}_i^1, \mathbf{c}_i^2, \dots, \mathbf{c}_i^N\} + \mathbf{t}_i)$ . In humans the agent-thing is the body and the constructs are the nervous system. In robots the agent-thing may be hardware and the constructs may be in software. In the FBS view presented in [13] an agent has “fixed structure”  $\mathbf{S}^f$  and “situated structure”  $\mathbf{S}^s$ , which are an agent-thing and constructs respectively. Although Gero’s  $f$  in  $\mathbf{S}^f$  means “fixed”, in general this need not be so. If a deaf person receives a cochlear implant their agent-thing changes. Presumably so does one or more constructs, otherwise the implant would be a waste.

The view of agency we hold builds on notions of memory that are often traced back to Dewey and Bartlett, although we use different descriptions. Memory is not understood primarily as allowing for the retrieval of an object from a data store by knowing its physical location. Memory is also not understood primarily as simply content-addressable: cue it with a fragment of what you want and it may be that the rest gets filled in but this is a side-effect not a primary effect. Rather, memory is guiding an experience in a fashion similar to how past experiences progressed, and recognising that this is so.

“We have had experiences; these exist stored up, in some unexplained way, in the mind, and when some experience occurs which is like some one of these, or has been previously contiguous with it in time or space, it calls this other up, and that constitutes memory. This, at most, solves but one half the problem. The association of ideas only accounts for the presence of the object or event. The other half is the reference of its present image to some past reality. In memory we re-cognize its presence; i.e., we know that it has been a previous element of our experience.” [14]

As Dewey [15] noted, an experience is not of a disembodied agent (although Dewey would not have used the word “agent”). It is to do with interaction of the agent with an environment. An experience is not something static; it is dynamic and is of certain kinds of entities that are coupled to their environment. This “entities ... coupled to their environment” is like Dewey’s experience changing “the objective conditions under which experiences are had” [16].

An agent  $\mathfrak{a}_i$  has experiences  $e_i^1, e_i^2 \dots e_i^N$ , where  $N$  is the number of experiences of  $\mathfrak{a}_i$ . A coupling between a pair of entities is at least one of the pair perturbing the state of the other. A coupling between  $(\xi - \mathfrak{a}_i)$  and an agent-thing  $\mathfrak{t}_i$  is an e-experience (exogenous experience) of  $\mathfrak{a}_i$ . A coupling between the agent-thing  $\mathfrak{t}_i$  and agent constructs  $\{\mathfrak{c}_i^j\}$ , or within  $\widehat{\mathfrak{c}}_i$ , is an a-experience (autogenous experience) of  $\mathfrak{a}_i$ .

In this work we describe the behaviour of an agent in terms of experiences, which are kinds of process. We also describe couplings between agents and external entities as perturbations by and of external processes. This means that we can use the process mereology “part of” relation on experiences. An experience is only an experience if it is of an embodied agent. Viewed from inside that agent it is called an experience, but experiences are processes of agents and an e-experience viewed from a non-agent thing or from another agent is a process. For one experience to perturb another requires that some experiences have parts that are themselves experiences, and that some experiences can be parts of multiple experiences. We write  $e^x \sqsubseteq e^y$  to mean “experience  $e^x$  is a part of experience  $e^y$ ”, we write  $e^x \sqsubset e^y$  to mean “experience  $e^x$  is a proper part of experience  $e^y$ ”, we write  $e^x \circ e^y$  to mean “experience  $e^x$  overlaps experience

$e^y$ ”, and we write  $e^x \mathbb{I} e^y$  to mean “experiences  $e^x$  and  $e^y$  are discrete”. Given these we say that when one experience perturbs another, or  $e_i^x \triangleright e_i^y$ , there will be some overlap between them. The following relations are derived from [17].

$$\begin{aligned}
e^x \circ e^y &\iff (\exists e^z \bullet e^z \sqsubseteq e^x \wedge e^z \sqsubseteq e^y) \\
e^x \mathbb{I} e^y &\iff \neg(e^x \circ e^y) \\
e^z = e^x + e^y &\implies \forall e^w \bullet (e^w \circ e^z \implies e^w \circ e^x \vee e^w \circ e^y) \\
e^z = e^x - e^y &\implies e^z \sqsubseteq e^x \wedge e^z \mathbb{I} e^y \\
e_i^x \triangleright e_i^y &\implies e^x \circ e^y
\end{aligned}$$

The  $+$  and  $-$  functions are commutative and associative [17] so we also define prefix versions that take a set of processes and return a process that is the result of folding the respective function through it. For example,

$$+\{e^x, e^y, e^z\} = e^x + e^y + e^z$$

For convenience we also define a time-constrained  $\triangleright$  relation:

$$\begin{aligned}
e_i^x \triangleright_{t_1, t_2} e_i^y &\implies \exists e_i^w, e_i^z \forall t_3 \bullet e_i^w \sqsubseteq e_i^x \wedge e_i^z \sqsubseteq e_i^y \wedge e_i^w \triangleright e_i^z \wedge \\
&\quad (t_1 \leq t_3 \leq t_2 \implies e_i^w(t_3) = e_i^x(t_3) \wedge \\
&\quad \quad e_i^z(t_3) = e_i^y(t_3))
\end{aligned}$$

Being processes, experiences have temporal extents that can be compared using interval relations like Allen’s [18] *start* and *during*. An experience *starts* when the agent activates an action that is qualitatively different from active experiences.

Experiences are situated unless stated otherwise: we use primed superscripts such as  $e_i^{x'}$  for this. Let the type of situation processes of agent  $\mathfrak{A}_i$  be  $\mathfrak{S}_i$  and the type of experiences be  $\mathfrak{E}_i$ . Suppose we fixate on an experience of an agent at a particular time: this fixation is a function from experiences of an agent onto its notions. We denote the type of notions of  $\mathfrak{A}_i$  as  $\mathfrak{N}_i$ . Combining and relating experiences or processes is via process mereology, combining and relating notions is via set operators, and converting an experience  $e$  to its notions  $n$  at time  $t$  is the  $()$  operator, or  $n = e(t)$ . If situations are processes that change how the agent interprets the environment,  $\mathfrak{S}_i$  will be a function on the agent’s experiences.

$$\mathfrak{S}_i : \mathfrak{N}_i \rightarrow \mathfrak{E}_i \rightarrow \mathfrak{E}_i$$

An un-situated experience  $e_i^{x'}$  is shaped one or more functions that each use another experience to influence this one. The idea is of the representation of the current situation arising from expectations:



- (i) An experience  $e_i^{x'}$  will be computed by one or more constructs  $\widehat{c}_i$ , and may be supervenient or emergent upon states of  $\widehat{c}_i$ .
- (ii) At current time  $t$ ,  $e_i^{x'}(t)$  involves notions  $n$  that vary in generality or abstractness. If we partition  $n$  into layers of similar generality, some will precede one or more others: let  $\prec_{\mathbb{G}}$  be a partial order such that  $\mathbf{n}_1 \prec_{\mathbb{G}} \mathbf{n}_2$  if notion  $\mathbf{n}_1$  is less general than  $\mathbf{n}_2$ .
- (iii) Each layer constructs a situation  $\mathfrak{s}_i^j$  that applies to layers that precede it according to the implemented  $\prec_{\mathbb{G}}$  relation. Situations that apply to  $e_i^{x'}$  at time  $t$  are applied to give  $e_i^x$  over temporal extent  $(t, t + \delta t)$ , or  $e_i^x = \mathfrak{s}_i^j(n)(e_i^{x'})$  for  $n \subseteq \cup e_i^y(t)$  where  $e_i^{x'} \prec_{\mathbb{G}} e_i^y$ .

Let  $issituated(e_i^x, t)$  be true if  $e_i^x$  is a situated experience at  $t$ . This requires that:

- The situated experience not be empty at  $t$ : that the notions  $e_i^x(t)$  not be  $\emptyset$ .
- That there be a situation process that it is the result of: there should be an  $\mathfrak{s}_i^j$  that constructs  $e_i^x$  from  $e_i^{x'}$ , or  $\exists \mathfrak{s}_i^j \exists e_i^y \bullet e_i^x(t) = \mathfrak{s}_i^j(e_i^y(t))(e_i^{x'})(t)$ .
- That the  $\mathfrak{s}_i^j$  it is the result of comes from an experience that is more general: that  $e_i^{x'} \prec_{\mathbb{G}} e_i^y$  where there is no  $e_i^z$  such that  $e_i^{x'} \prec_{\mathbb{G}} e_i^z \prec_{\mathbb{G}} e_i^y$ .

Putting these together,

$$\begin{aligned}
issituated(e_i^x, t) &= e_i^x(t) \neq \emptyset \wedge \\
&\quad \exists \mathfrak{s}_i^j \exists e_i^y \bullet e_i^x(t) = \mathfrak{s}_i^j(e_i^y(t))(e_i^{x'})(t) \wedge \\
&\quad e_i^{x'} \prec_{\mathbb{G}} e_i^y \wedge \\
&\quad (\nexists e_i^z \bullet e_i^{x'} \prec_{\mathbb{G}} e_i^z \prec_{\mathbb{G}} e_i^y)
\end{aligned}$$

Context comes from those entities outside of an agent that it is aware of its interactions with. A useful characterisation comes from [19]:

“The context is thus a frame (Goffman 1974) that surrounds the event being examined and provides resources for its appropriate interpretation ... The notion of context thus involves a fundamental juxtaposition of two entities: (1) a focal event; and (2) a field of action within which that event is embedded” .

“Field” here has its common language meaning not its mathematical one, and “frame” has its sociology meaning not its AI one. We shall avoid using either word. Context is *outside* of the agent but only comes from those entities and perturbations that the agent is aware of. What is inside the agent are situations plus sense-data, percepts, concepts, acts and effect-data, some of which we could label “the interpretation of the current context”. Situations determine what goes on inside an agent, hence what the agent is aware of. Consequently what is in the context of an agent at some time depends on the situation. Conversely the context influences the agent’s interpretation of the

environment and hence the situation.

If an agent activating an action *starts* an e-experience  $\mathbf{e}_i^x$ , that is a “focal event”. If an agent  $\mathfrak{a}_i$  activating an action *starts* an e-experience  $\mathbf{e}_i^x$ , the “field of action” of the context for  $\mathfrak{a}_i$  are from those entities that the agent is aware of.

Designing is about envisioning new worlds but the artefacts of these have properties that are all of the three FBS [20] types function **F**, behaviour **B**, and structure **S**. FBS is ontology with respect to design but we don’t necessarily expect to see concrete implemented representations in agents in this form. It may be that a design agent represents domain knowledge concepts in OWL [21] or some other ontology language. It may also be that a design agent represents domain knowledge concepts using a distributed memory such that observers could describe its behaviour using FBS but without the agent ever using FBS directly. We will write  $\mathbf{e}(t) \rightsquigarrow \mathbf{s}$  to denote that the notions of experience  $\mathbf{e}$  at time  $t$  could be describing as representing a structure  $\mathbf{s}$  (similarly for behaviour and FBS function).

All external entities that the agent could possibly sense or effect we call the external world of the agent. The term “external world” comes from sFBS [22], which is FBS applied to situated designing. For an agent  $\mathfrak{a}_i$ ,

- The external world  $\mathbf{w}_i^x$  of  $\mathfrak{a}_i$  is part of the environment, or  $\mathbf{w}_i^x \sqsubseteq (\xi - \mathfrak{a}_i) + \mathfrak{t}_i$ ,
- The interpreted world  $\mathbf{w}_i^x$  of  $\mathfrak{a}_i$  are experiences of  $\{\mathbf{c}_i^1, \mathbf{c}_i^2, \dots, \mathbf{c}_i^N\}$  together with part of the experiences of  $\mathfrak{t}_i$ ,
- The expected world  $\mathbf{w}_i^x$  of  $\mathfrak{a}_i$  are part of the experiences of  $\mathbf{w}_i^x$ .

According to sFBS, the environment contains  $3N$  worlds some of which overlap, where  $N$  is the number of agents. As some part of the environment must be in the context of each agent and context for an agent is part its external world, the external worlds of the agents overlap. Overlaps between  $\mathbf{w}_i^x$  and  $\mathbf{w}_i^x$  are of perturbations:  $\mathbf{w}_i^x$  supports processes,  $\mathbf{w}_i^x$  has experiences, these perturb each other in e-experiences, and those perturbations require overlaps. Perturbations are of four kinds: data push out, data push in, expectation changes, and data pull. Let  $procs(\mathbf{o})$  be the processes (for things) and experiences (for agents) of entities  $\{\mathbf{o}\}$

$$procs : \mathbb{P}\mathbf{O} \rightarrow \mathbb{P}\mathbf{P}$$

where  $\mathbb{P}$  indicates a power set,  $\mathbf{O}$  is the type of entities,  $\mathbf{P}$  is the type of processes, and where experiences are types of process. So  $p \in procs(\{\mathbf{o}\})$  if process  $p$  is supported by entity  $\mathbf{o}$ . Perturbations on processes of  $\mathbf{w}_i^x$  by  $\mathbf{w}_i^x$  are

data push out  $\mathbf{u}_i^x$  by  $\mathfrak{A}_i$ .

$$\begin{aligned}\mathbf{u}_i^x(t) &= \left( + \{ \mathbf{e}_i^x \mid \mathbf{e}_i^x \in \mathbf{w}_i^x \wedge (\exists \mathbf{p} \in \text{procs}(\mathbf{w}_i^x) \bullet \mathbf{e}_i^x \triangleright_{t,t+\delta t} \mathbf{p}) \} \right)(t) \\ \mathbf{u}_i^x &= + \{ \mathbf{e}_i^x \mid \mathbf{e}_i^x \in \mathbf{w}_i^x \wedge (\exists \mathbf{p} \in \text{procs}(\mathbf{w}_i^x) \bullet \mathbf{e}_i^x \triangleright \mathbf{p}) \}\end{aligned}$$

Perturbations on  $\mathbf{w}_i^x$  by processes of  $\mathbf{w}_i^x$  are data push in  $\mathbf{u}_i^x$ . They are new low level inputs triggering “what do I look like now?” in  $\mathfrak{A}_i$ .

$$\begin{aligned}\mathbf{u}_i^x(t) &= \left( + \{ \mathbf{e}_i^x \mid \mathbf{e}_i^x \in \mathbf{w}_i^x \wedge (\exists \mathbf{p} \in \text{procs}(\mathbf{w}_i^x) \bullet \mathbf{p} \triangleright_{t,t+\delta t} \mathbf{e}_i^x) \} \right)(t) \\ \mathbf{u}_i^x &= + \{ \mathbf{e}_i^x \mid \mathbf{e}_i^x \in \mathbf{w}_i^x \wedge (\exists \mathbf{p} \in \text{procs}(\mathbf{w}_i^x) \bullet \mathbf{p} \triangleright \mathbf{e}_i^x) \}\end{aligned}$$

Perturbations on  $\mathbf{w}_i^x$  by  $\mathbf{w}_i^x$  are data push in  $\mathbf{u}_i^x$ .

$$\begin{aligned}\mathbf{u}_i^x(t) &= \left( + \{ \mathbf{e}_i^x \mid \mathbf{e}_i^x \in \mathbf{w}_i^x \wedge (\exists \mathbf{e}_i^y \in \mathbf{w}_i^x \wedge \mathbf{e}_i^x \neq \mathbf{e}_i^y \wedge \mathbf{e}_i^x \triangleright_{t,t+\delta t} \mathbf{e}_i^y) \} \right)(t) \\ \mathbf{u}_i^x &= + \{ \mathbf{e}_i^x \mid \mathbf{e}_i^x \in \mathbf{w}_i^x \wedge (\exists \mathbf{e}_i^y \in \mathbf{w}_i^x \wedge \mathbf{e}_i^x \neq \mathbf{e}_i^y \wedge \mathbf{e}_i^x \triangleright \mathbf{e}_i^y) \}\end{aligned}$$

$\mathbf{w}_i^x$  and  $\mathbf{w}_i^x$  perturb each other, and  $\mathbf{w}_i^x$  and  $\text{procs}(\mathbf{w}_i^x)$  perturb each other.  $\mathbf{w}_i^x$  and  $\text{procs}(\mathbf{w}_i^x)$  usually would not perturb each other but this is not specifically precluded. As an agent interacts with its environment, we assume that a design agent will have at least one data push.

$$\mathbf{u}_i^x \cup \mathbf{u}_i^x \neq \emptyset$$

Notice that  $\mathbf{u}_i^x$  and  $\mathbf{u}_i^x$  are defined relative to  $\mathfrak{A}_i$ 's experiences, not relative to external entities. The issue here is whether there are experiences of  $\mathfrak{A}_i$  perturbing ( $\xi - \mathfrak{A}_i$ ) or being perturbed by  $\mathfrak{A}_i$  perturbing ( $\xi - \mathfrak{A}_i$ ), not the identity of whatever it is that actually comprises this ( $\xi - \mathfrak{A}_i$ ). Perturbations on  $\mathbf{w}_i^x$  by  $\mathbf{w}_i^x$  are changes to expectations  $\mathbf{h}_i$  that bias data push belief propagation. They are new high level representations of  $\mathfrak{A}_i$  triggering “I would prefer it if I looked like this”.

$$\begin{aligned}\mathbf{h}_i(t) &= \left( + \{ \mathbf{e}_i^x \mid \mathbf{e}_i^x \in \mathbf{w}_i^x \wedge (\exists \mathbf{e}_i^y \in \mathbf{w}_i^x \wedge \mathbf{e}_i^x \neq \mathbf{e}_i^y \wedge \mathbf{e}_i^x \triangleright_{t,t+\delta t} \mathbf{e}_i^y) \} \right)(t) \\ \mathbf{h}_i &= + \{ \mathbf{e}_i^x \mid \mathbf{e}_i^x \in \mathbf{w}_i^x \wedge (\exists \mathbf{e}_i^y \in \mathbf{w}_i^x \wedge \mathbf{e}_i^x \neq \mathbf{e}_i^y \wedge \mathbf{e}_i^x \triangleright \mathbf{e}_i^y) \}\end{aligned}$$

Data pull  $\mathbf{v}_i$  are the situation of  $\mathfrak{A}_i$  changing the construction of particular data. They are new high level representations triggering “I want you to look

like this!”.

$$\begin{aligned}
\mathbf{v}_i(t) &= \left( + \{ \mathbf{e}_i^x \mid \mathbf{e}_i^x \in \mathbf{w}_i^{\mathcal{H}} \wedge \right. \\
&\quad \left. (\exists \mathbf{e}_i^y \in \mathbf{w}_i^{\mathcal{T}} \bullet \mathbf{e}_i^x \neq \mathbf{e}_i^y \wedge \mathbf{e}_i^x \triangleright_{t,t+\delta t} \mathbf{e}_i^y \wedge \right. \\
&\quad \left. \text{issituated}(\mathbf{e}_i^x, t) \wedge \text{issituated}(\mathbf{e}_i^y, t)) \} \right)(t) \\
\mathbf{v}_i &= + \{ \mathbf{e}_i^x \mid \mathbf{e}_i^x \in \mathbf{w}_i^{\mathcal{H}} \wedge \\
&\quad (\exists \mathbf{e}_i^y \in \mathbf{w}_i^{\mathcal{T}} \bullet \mathbf{e}_i^x \neq \mathbf{e}_i^y \wedge \mathbf{e}_i^x \triangleright \mathbf{e}_i^y \wedge \\
&\quad \text{issituated}(\mathbf{e}_i^x, t) \wedge \text{issituated}(\mathbf{e}_i^y, t)) \}
\end{aligned}$$

Context is in  $\xi$  but what, rather than just being  $\text{procs}(\mathbf{w}_i^x)$ , makes processes part of the context for  $\mathfrak{a}_i$  during  $(t, t + \delta t)$  is the situation at  $t$ . It is that part of  $\xi$  that the agent can interact with and that it is aware of its interactions with. Let  $\hat{p}_i$  be the potential context of  $\mathfrak{a}_i$ :

$$\hat{p}_i = \{ \mathbf{p} \mid \mathbf{p} \in \text{procs}(\mathbf{w}_i^x) \wedge (\exists \mathbf{e}_i^x \bullet \mathbf{e}_i^x \in \mathbf{w}_i^{\mathcal{T}} \wedge (\mathbf{p} \triangleright \mathbf{e}_i^x \vee \mathbf{e}_i^x \triangleright \mathbf{p})) \}$$

To clarify this,  $\text{procs}(\mathbf{w}_i^x)$  are all processes of  $(\xi - \mathfrak{a}_i)$  that could ever possibly perturb or be perturbed by  $\mathfrak{a}_i$  directly or indirectly, together with those of  $\mathfrak{t}_i$  that overlap these external processes.  $\hat{p}_i$  are those of  $\text{procs}(\mathbf{w}_i^x)$  that do perturb or are perturbed by experiences from  $\mathbf{w}_i^{\mathcal{T}}$ , whether  $\mathfrak{a}_i$  is aware of the perturbation or not. Context are those of  $\hat{p}_i$  that  $\mathfrak{a}_i$  interacts with and is aware of doing so.

Let  $\text{ispath}(\mathbf{p}^x, \mathbf{p}^y, t_1, t_2)$  be true if process or experience  $\mathbf{p}^x$  perturbs process or experience  $\mathbf{p}^y$  during  $(t_1, t_2)$ :

$$\begin{aligned}
\text{ispath}(\mathbf{p}^x, \mathbf{p}^y, t_1, t_2) &= \mathbf{p}^x \triangleright_{t_1, t_2} \mathbf{p}^y \vee \\
&\quad \mathbf{p}^y \triangleright_{t_1, t_2} \mathbf{p}^x \vee \\
&\quad (\exists \mathbf{p}^z \exists t_3 \bullet \text{ispath}(\mathbf{p}^x, \mathbf{p}^z, t_1, t_3) \wedge \\
&\quad \quad (\mathbf{p}^z \triangleright_{t_3, t_2} \mathbf{p}^y \vee \mathbf{p}^y \triangleright_{t_3, t_2} \mathbf{p}^z)) \\
\text{ispath}(\mathbf{p}^x, \mathbf{p}^y) &= \text{ispath}(\mathbf{p}^x, \mathbf{p}^y, -\infty, \infty)
\end{aligned}$$

Given these, we say that every process in the context of  $\mathfrak{a}_i$  in  $(t, t + \delta t)$  relates to a situated experience in  $(t, t + \delta t)$ . We denote the context of  $\mathfrak{a}_i$  as  $\mathbf{r}_i$  and the context of  $\mathfrak{a}_i$  during  $(t, t + \delta t)$  as  $\mathbf{r}_i(t)$ :

$$\begin{aligned}
\mathbf{r}_i(t) &= \left( + \{ \mathbf{p} \mid \mathbf{p} \in \hat{p}_i \wedge \right. \\
&\quad \left. (\exists \mathbf{e}_i^x \bullet \text{ispath}(\mathbf{p}, \mathbf{e}_i^x, t, t + \delta t) \wedge \text{issituated}(\mathbf{e}_i^x, t)) \} \right)(t)
\end{aligned}$$

As situated experiences may change over time, the implication is that what counts as context also may change even if the external processes don't them-

selves change.

$$\begin{aligned} \mathbf{r}_i &= +\{\mathbf{p} \mid \mathbf{p} \in \widehat{p}_i \wedge (\exists \mathbf{e}_i^x \exists t \bullet \text{ispath}(\mathbf{p}, \mathbf{e}_i^x) \wedge \text{issituated}(\mathbf{e}_i^x, t))\} \\ \mathbf{r}_i &\sqsubseteq +\widehat{p}_i \sqsubseteq +\text{procs}(\mathbf{w}_i^x) \sqsubseteq +\text{procs}(\xi) \end{aligned}$$

### 3 Context, situations, and common ground

In this section we use the session shown in Figure 1 for three examples of the role of context and situations to design agents: (i) sketching over an old drawing, (ii) common ground, and (iii) indexicals and gestures. The design session was recorded for the “Team Collaboration in High Bandwidth Virtual Environments” project [8] and was part of a baseline study of conceptual designing. The session took place at an architect’s office and involved two designers continuing the conceptual design of a proposed site. We refer to the designers as agents. The designer that we shall call  $\mathfrak{a}_d$  can be seen at the top of Figure 1(b). The designer that we shall call  $\mathfrak{a}_n$  can be seen at the left of Figure 1(b).  $\mathfrak{a}_d$  is the more senior designer and leads the session. As can be seen in Figure 1(a), the current building design is of two main parts bent around a central atrium. Notice the annotations made on that drawing by the designers, one of which is VIEW 2 next to an arrow? The atrium is the dark vertical mass pointed at by VIEW 2 and which we shall refer to as *atrium*. *lhs* and *rhs* shall refer to the main masses to the left and right of *atrium* with respect to VIEW 2. The session begins with  $\mathfrak{a}_d$  sketching the floor plan shown in Figure 1(c) and progresses to sketching the section shown in Figure 1(d). The agents observe their environment and perform actions that change both the environment as well as the relations between the agents and their environment. Their experiences of these actions include discussing requirements, formalising design problems, making design descriptions, interpreting design descriptions, and so on.

$$\begin{aligned} \mathbf{w}_d^x &= \{\mathfrak{t}_d, \mathfrak{a}_n, \mathfrak{t}_{\text{desk}}, \dots\} \\ \mathbf{w}_n^x &= \{\mathfrak{t}_n, \mathfrak{a}_d, \mathfrak{t}_{\text{desk}}, \dots\} \\ +\text{procs}(\mathbf{w}_d^x) &\sqsubseteq \text{procs}(\xi) \wedge +\text{procs}(\mathbf{w}_n^x) \sqsubseteq \text{procs}(\xi) \end{aligned}$$

$\mathbf{w}_n^x$  looks similar to  $\mathbf{w}_d^x$  because the session is synchronous at one location. For  $\mathfrak{a}_d$ ,  $\mathbf{w}_d^x$  is e-experiences driving effect-data:

- For speech acts, where entities of  $\mathfrak{t}_d$  perturb the air in the room,
- For sketch acts, where entities of  $\mathfrak{t}_d$  perturb the pen entity that  $\mathfrak{a}_d$  holds,
- For body movement acts, where  $\mathfrak{a}_d$  perturbs parts of  $\mathfrak{t}_d$  he believes are visible by  $\mathfrak{a}_n$ .

Body movement [23] includes (i) postures, such as one agent conveying a friendly body position to another, (ii) head movement and facial expressions, such as a listening agent conveying interest, understanding and agreement to a speaking agent, and (iii) and gestures, such as to point to something on a sketch.  $\mathbf{u}_d^x$  is e-experiences driving sense-data:

- For sound, where speech of  $\mathfrak{A}_d$ ,  $\mathfrak{A}_n$ , the camera operator, other nearby but unseen persons, and other background noise perturbs entities of  $\mathfrak{T}_d$  that receive sound (hearing);
- For vision, where light incident off sketches, drawings, pens, photos, the room and its parts (floor, walls, windows, ...), the desk and chairs, the video camera and microphone,  $\mathfrak{A}_d$ ,  $\mathfrak{A}_n$ , and so on perturb entities of  $\mathfrak{T}_d$  that receive light (vision);
- Other perturbations, not necessarily recognised in sense-data, of  $\mathfrak{A}_d$  that he may not be aware of such as room temperature and humidity being perturbed by the air conditioning.

### 3.1 Example: sketching over an old drawing

The first example of context and situations is  $\mathfrak{A}_d$  sketching on a clean sheet of tracing paper placed over an older drawing of the same building, with other sketches and drawings spread out within view. Changes to these parts of the environment become the context of  $\mathfrak{A}_d$ 's interactions.  $\mathfrak{A}_d$  speaks as he sketches but the sketches, speech and gestures do not always make sense beyond the session. The sketches are conceptual and his speech is full of indexical references and accompanying gestures. Both designers sketch at times - on the same or separate sketches - and speak while the other observes and listens, and other times continue sketching and talking as though the other is observing even though they are not.

As  $\mathfrak{A}_d$  is an open system and as the environment is larger than his experiences or interpretation of it, understanding context is vital to understanding his behaviour. The response to the environment by this open system depends on his current inputs and the history of his interactions. An agent recording and using its history is infeasible so the usual computational "convenience" [24] is an approximation as some internal state. In our agents this is an interpreted world providing interpretations of the current state of the agent and its context.

$$\exists f \bullet \mathbf{u}_d^x(t + \delta t) = f(\mathbf{u}_d^x(-\infty, t), \mathbf{u}_d^x(t))$$

We are considering coupled, non-trivial, open systems though:

“the past provides no basis for the prediction of the future owing to the con-

tinual creation of ‘new initial conditions’ that have never been experienced before (each present state of a chaotic dynamical system is a nontrivial initial condition for all future states)” [25].

At one point during the session the immediate design goal is movement across the atrium between *lhs* and *rhs*. To this end  $\mathfrak{a}_d$  and  $\mathfrak{a}_n$  are discussing internal bridges.  $\mathfrak{a}_d$  points to the atrium and says “lets talk pure notional diagram of the space. How are we going to make the space interesting?”.  $\mathfrak{a}_d$  sketches, on the tracing paper placed over an old drawing, a narrow bridge right-angled across the void. He says “What I’m looking for is you don’t want to do that”, indicating a wide arc for the path walked by pedestrians that this sketched bridge implies. Let this time be  $t_b$ , where  $\mathfrak{a}_d$  has notions  $\mathbf{u}_d^x(t)$  some of which we could describe as representing building FBS. If  $\mathbf{u}_d^x(t_b) \rightsquigarrow \{\mathbf{s}_d^{t_b}, \mathbf{b}_d^{t_b}, \mathbf{f}_d^{t_b}, \dots\}$ ,

- $\mathbf{f}_d^{t_b}$  includes what  $\mathfrak{a}_d$  understands the required building FBS functions to be. Part of this is movement across *atrium* between *lhs* and *rhs*.
- $\mathbf{s}_d^{t_b}$  includes what  $\mathfrak{a}_d$  understands the current building structure to be. He interprets it from the available sketches, drawings, discussions with others, and from his memories.
- $\mathbf{b}_d^{t_b}$  includes what  $\mathfrak{a}_d$  understands the behaviours of  $\mathbf{s}_d^{t_b}$  to be as well as what he understands the behaviours required by  $\mathbf{f}_d^{t_b}$  to be. He interprets these from how he expects  $\mathbf{s}_d^{t_b}$  to behave and how he wants  $\mathbf{f}_d^{t_b}$  to behave.

The agent’s part in the agent-context coupling is simplified by  $\mathbf{u}_d^x$  not having to contain a detailed model, FBS or otherwise, of the old drawing because he can see it through the new sheet. His production of the current context is made simpler because of this. The old drawing is a large part of  $\mathfrak{a}_d$ ’s environment as it acts both as a guide for sketching actions and as an external representation of structure detail. Especially relevant to  $\mathbf{s}_d^{t_b}$  is structure from the older drawing and especially relevant to  $\mathbf{r}_d(t_b)$  is that older drawing. Interpreted structure of the bridge is relative to  $\mathbf{s}_d^{t_b}$  represented externally in the context of the older drawing. Similarly, when  $\mathfrak{a}_d$  indicates that pedestrian behaviour is not what he likes it is via a sketched and gestured arc that also is relative to the context of the older drawing and to the context of the newly sketched bridge. The behaviour of  $\mathfrak{a}_d$  demonstrates clearly the Dorst and Dijkhuis [26] statement that the unit of design is action.  $\mathfrak{a}_d$  doesn’t ponder a problem and then document the solution; he interacts with an external representation of it, repeatedly changing the context, and he discovers the solution in that external representation.

Ongoing interpretations change the situation, as shown in Figure 3.  $\mathbf{u}_d^x(t_b)$  are interpreted in  $\mathbf{u}_d^x$  and  $\mathbf{u}_d^{x'}$  in the light of  $\mathbf{s}_d^{t_b}$ .  $\mathbf{u}_d^{x'}(t_b)$  are generated from  $\mathbf{u}_d^x$  in the light of  $\mathbf{s}_d^{t_b}$ , and  $\mathbf{u}_d^x(t_b)$  leads to expectations in  $\mathbf{u}_d^{x'}$  of forthcoming interpretations. Certain actions in  $\mathbf{u}_d^{x'}(t_b)$  given situation  $\mathbf{s}_d^{t_b}$  appear more suitable than others. Activating those actions results in perturbations of entities

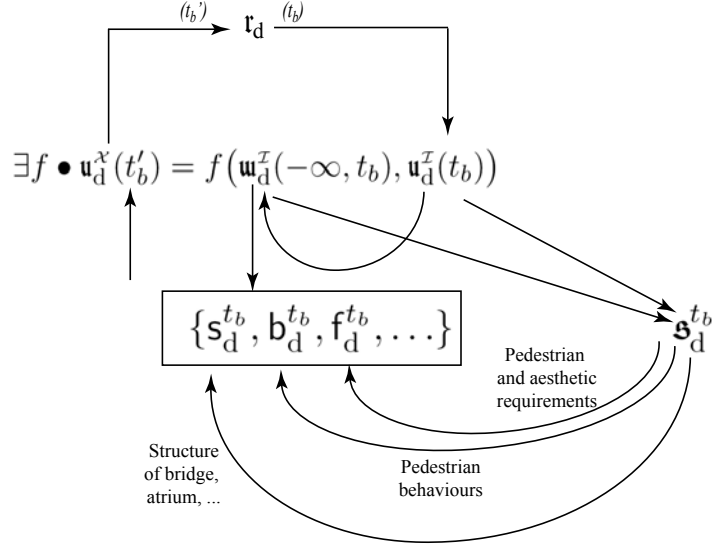


Fig. 3. Context and situation for  $\mathfrak{a}_d$  of bridge example.

from  $\mathfrak{u}_d^x$ . Those perturbed entities perturb others in turn, some of which are pulled or pushed as inputs to be interpreted as entities (other agents, persons, and things) from the context of  $\mathfrak{a}_d$ . If nothing unexpected occurs, the updated  $\mathfrak{u}_d^z(t_b + \Delta t)$  remains consistent with the  $\mathfrak{s}_d^{t_b}$  and  $\mathfrak{u}_d^z(t_b)$  that led to those actions. Occasionally something unexpected may occur such as unexpected changes to sense-data or expected changes to sense-data not arising. Such cases lead to learning by the agent, or to revised expectations and hence a new situation, interpretation, and hence context. For  $\mathfrak{a}_d$  this is  $\mathfrak{s}_d^{t_b}$  trying, unsuccessfully, to interpret the currently sketched bridge structure according to his desires of bridge function and behaviour. So  $\mathfrak{a}_d$  acts on  $\mathfrak{r}_d(t'_b)$ , where  $t'_b = t_b + \Delta t$ , trying an alternative sketch of a wider bridge that parallels the lines of *rhs*. Paralleling *rhs* makes it angled with respect to *lhs* and *atrium*.  $\mathfrak{a}_d$  says “I quite like that bridge” as he gestures to the parallel lines. Now with  $\mathfrak{s}_d^{t'_b}$  he interprets the currently sketched bridge structure successfully according to his desires of bridge function and behaviour.

$\mathfrak{a}_d$  and  $\mathfrak{a}_n$  communicate synchronously at the same location so they clearly share the environment. It may also appear that they share much of the same context but that need not be so. This is because past experiences of  $\mathfrak{a}_d$  and  $\mathfrak{a}_n$  differ, so situation processes in  $\mathfrak{S}_n$  differ from situation processes in  $\mathfrak{S}_d$ , as do  $\mathfrak{u}_n^z$  and  $\mathfrak{u}_n^{z'}$  from  $\mathfrak{u}_d^z$  and  $\mathfrak{u}_d^{z'}$ . Part of  $\mathfrak{u}_d^x$  is speech and gestures directed at  $\mathfrak{a}_n$ , part of  $\mathfrak{u}_n^x$  is speech and gestures directed at  $\mathfrak{a}_d$ , and part of both  $\mathfrak{u}_d^z$  and  $\mathfrak{u}_n^z$  comes from observing the same sketches at the same time.  $\mathfrak{u}_d^z$  at  $t$  depends on  $\mathfrak{r}_d$  until  $t$  which in turn depends on  $\mathfrak{s}_d^t$  and  $\mathfrak{u}_d^z$ , similarly for  $\mathfrak{a}_n$ . Now  $\mathfrak{r}_d \sqsubset +procs(\xi)$  but what parts of  $+procs(\xi)$  are in  $\mathfrak{r}_d$  depends on  $\mathfrak{s}_d$ , similarly for  $\mathfrak{r}_n$ . But as these contexts are from the environment and as we know that  $\mathfrak{a}_d$  communicates with  $\mathfrak{a}_n$ , we can say that the contexts of  $\mathfrak{a}_d$  and  $\mathfrak{a}_n$  overlap, or  $\mathfrak{r}_d \cap \mathfrak{r}_n \neq \emptyset \wedge \mathfrak{r}_d \neq \mathfrak{r}_n$ . This what we mean when we say that



communicating agents have “shared context”.

### 3.2 Example: common ground

The second example of context and situations is common ground. Each agent interprets the world from memories of their own past experiences and their own interpretation of the current situation. Even so, when  $\mathfrak{a}_d$  says “I quite like that bridge” he intends for some of his  $\mathfrak{s}_d^{tb}$  to be interpreted similarly by  $\mathfrak{a}_n$  as  $\mathfrak{s}_n^{tb}$ . This is despite  $\mathfrak{a}_d$  having only sketching a rough pair of parallel lines. An *atrium* bridge as interpreted by  $\mathfrak{a}_d$  in  $\mathfrak{s}_d^{tb}$  is conceptually very far from these rough lines. To cross this conceptual distance clearly requires architectural notions but it also requires common ground.

“For communication between interacting agents to succeed there needs to be a common ground (Clark 1992). This notion affirms that these agents have constructed appropriate models of each other to an extent sufficient for the purpose of the current interaction. Common ground is thus an emergent property of the current interaction” [13, Section 4].

The “common” in “common ground” suggests that something overlaps, otherwise there would be nothing common. But no belief of  $\mathfrak{a}_d$  could ever actually overlap with any belief of  $\mathfrak{a}_n$ . When *we* say “common ground” we refer to a notion with two aspects that correspond to our distinguishing contexts from situations.

The first aspect of common ground concerns contexts and relates back to Section 3.1. Even agents in different physical or temporal locations need a medium that provides an overlap of their contexts or they could not communicate: letters passed via the Post Office, Morse code via a telegraph line, email via the Internet, avatars and chat via a virtual world, whatever. For  $\mathfrak{a}_d$  and  $\mathfrak{a}_n$  this medium is straight forward as they are embodied at the same time and place. When  $\mathfrak{a}_d$  says the word “bridge” it is with both agents looking at the same sketch and with both already having similar interpretations  $\mathfrak{w}_i^x(tb) \rightsquigarrow \{\mathfrak{s}_i^{tb}, \mathfrak{b}_i^{tb}, \mathfrak{f}_i^{tb}, \dots\}$  for  $i \in \{d, n\}$ , constructed during this and past design sessions from interactions with contexts  $\mathfrak{r}_d \circ \mathfrak{r}_n$ . Their coming to similar interpretations depends on their sharing some of this context, and one role of their speaking and gesturing to each other is ensuring that their respective situation processes focus their respective attentions such that it is so.

The other aspect of common ground concerns situations and so relates to how each interprets their inputs and outputs (that is,  $(\mathfrak{u}_i^x + \mathfrak{u}_i^x)$  for  $i \in \{d, n\}$ ).  $\mathfrak{a}_d$  works so that  $\mathfrak{a}_d$  has the belief that  $\mathfrak{a}_n$  understands words and sketches as  $\mathfrak{a}_d$  does, and vice versa for  $\mathfrak{a}_n$ . He wants to believe that there is something they both believe the same of. The agent works at this partly by acting on the en-

vironment: speaking, gesturing, sketching, adopting appropriate postures and facial expressions, and so on. The agent also works by the process described in Section 3.1: updating the interpreted world, expected world, situation processes, and adapting by updating memory for future similar situations.

“In dialogue, speakers try to *ground* their communicative acts as they go along: They work with their partners to reach the mutual belief that the partners have understood them well enough for current purposes” [27, emphasis is the authors’].

A demonstration of the origin of this is Steels’ [28] “naming game”: a speaker picks an entity that it perceives from the environment and communicates its name for it to a hearer, whereupon a hearer points to the entity from the environment that the hearer understands to have that name. This gives both the chance of learning common ground. Recent web technologies like the collaborative tagging in Flickr also provide a crude example of how this can work [28]. The agents cannot know for sure how another interprets the environment, as each maintains its own representations of what signifiers mean, and each learns by dynamic negotiation and “repairing miscommunications”.

A clear example of the importance of common ground or the lack of it is experts collaborating who are from different design domains. Gero and Kannengiesser [13] use FBS to this end, where the experts may be people, artificial agents, or intelligent interfaces between CAD packages from varying design domains. Figure 4 illustrates the idea but remember that when Gero and Kannengiesser show beliefs of  $\mathfrak{a}_d$  about  $\mathfrak{a}_n$  as one FBS model drawn inside another, they mean ontologically only. It is possible for such FBS models to emerge from interac-

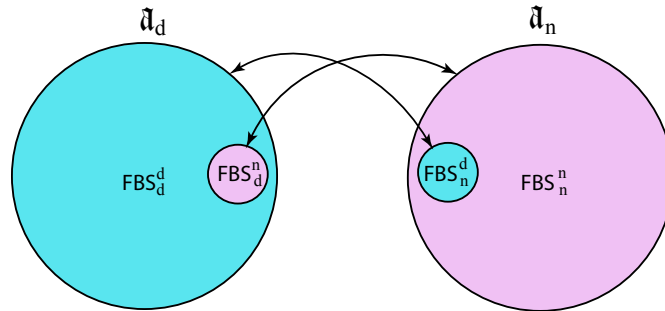


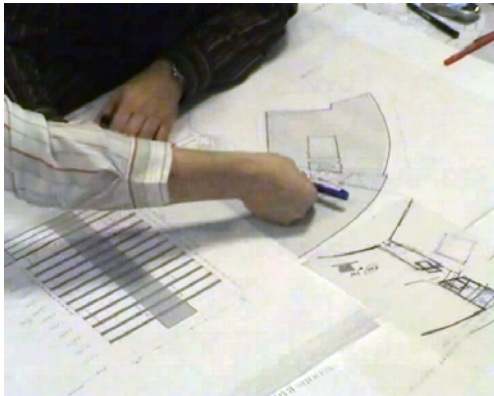
Fig. 4. “Pairs of consistent FBS models that establish the common ground of two agents”, adapted from [13, Figure 3] with superscripts/subscripts reversed to avoid confusion, and agents changed to  $\mathfrak{a}_d$  and  $\mathfrak{a}_n$ .

tions among the agent’s experiences. There is no requirement that an agent literally have a representation of another agent that it uses to “plan” communications.  $FBS_n^d$  is the FBS *model* of  $\mathfrak{a}_d$  constructed by  $\mathfrak{a}_n$  but in terms of agent constructs and processes this may only be emergent within  $\mathfrak{a}_n$ . If we could inspect the concrete representations of  $\mathfrak{a}_n$  we may find nothing corresponding

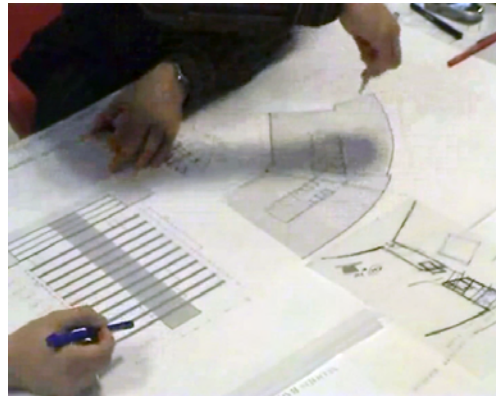
directly with  $FBS_n^d$ . Some of what we describe as  $FBS_n^d$  may only be emergent within  $\mathfrak{a}_n$  but it would be too severe to say that all common ground is emergent. Some will be recalled from  $\mathfrak{u}_n^z$  (and similarly from  $\mathfrak{u}_d^z$ ), others emerged. The word “consistent” in the caption on Figure 4 is only with respect to the interpreted and expected worlds of an agent. It only indicates that memories of  $\mathfrak{a}_n$  are consistent with  $\mathfrak{a}_n$ ’s previous experiences of interacting with  $\mathfrak{a}_d$ . There is no claim being made about the consistency of  $\mathfrak{a}_n$ ’s internal representations with  $\mathfrak{a}_d$ ’s internal representations. Further, as the agent is constructive, this consistency is only on currently constructed memories.

### 3.3 Example: indexicals and gestures

The third example of context and situations is indexicals and gestures. When  $\mathfrak{a}_d$  says “I quite like that bridge” it raises another problem: what to do on other floors? They don’t like a stack of these angled bridges on all floors up through *atrium*.  $\mathfrak{a}_d$  suggests a central angled bridge on some floors, with a pair of bridges at the ends of *atrium* on alternating floors.  $\mathfrak{a}_d$  tries a thumbnail 3D projection while discussing it with  $\mathfrak{a}_n$ . It appears that this is successful enough to not be rejected but needs further investigation:  $\mathfrak{a}_d$  says “can we draw the section of what this”, points to the void where the alternating bridges could go, says “... lets overlay it ... on that CAD section”, and later says “we are starting to get something interesting”. They start working on a section view.  $\mathfrak{a}_n$  pulls out a drawing seen on the desk in Figure 1(b) and lays tracing paper over it on which to sketch.  $\mathfrak{a}_d$  starts sketching.  $\mathfrak{a}_n$  says “we should be going that way” and gestures (Figure 5(a)) along *atrium*.  $\mathfrak{a}_d$  replies “yeh, we are going to cut through here”, points to a section through the *atrium*, “looking there” and points toward *rhs* where it faces the *atrium* (Figure 5(b)).



(a)  $\mathfrak{a}_n$  speaks and gestures ( $g_1$ )



(b)  $\mathfrak{a}_d$  replies and gestures ( $g_2$  and  $g_3$ )

Fig. 5. More images from [8]

The following is the last part of the above communication.

$\mathfrak{a}_d$ : “yeh, we are going to cut through here looking there”  
 $[ \quad \quad \quad \mathfrak{a}_n : g_1 \quad ]$   
 $[ \quad \quad \quad \mathfrak{a}_d : g_2 \quad ] [ \mathfrak{a}_d : g_3 \quad ]$

Gestures are annotated using square brackets [29], with  $g_1$  being the Figure 5(a) gesture by  $\mathfrak{a}_n$  and  $g_3$  the Figure 5(b) gesture by  $\mathfrak{a}_d$ . A partial interpretation by  $\mathfrak{a}_n$  is shown as Figure 6.

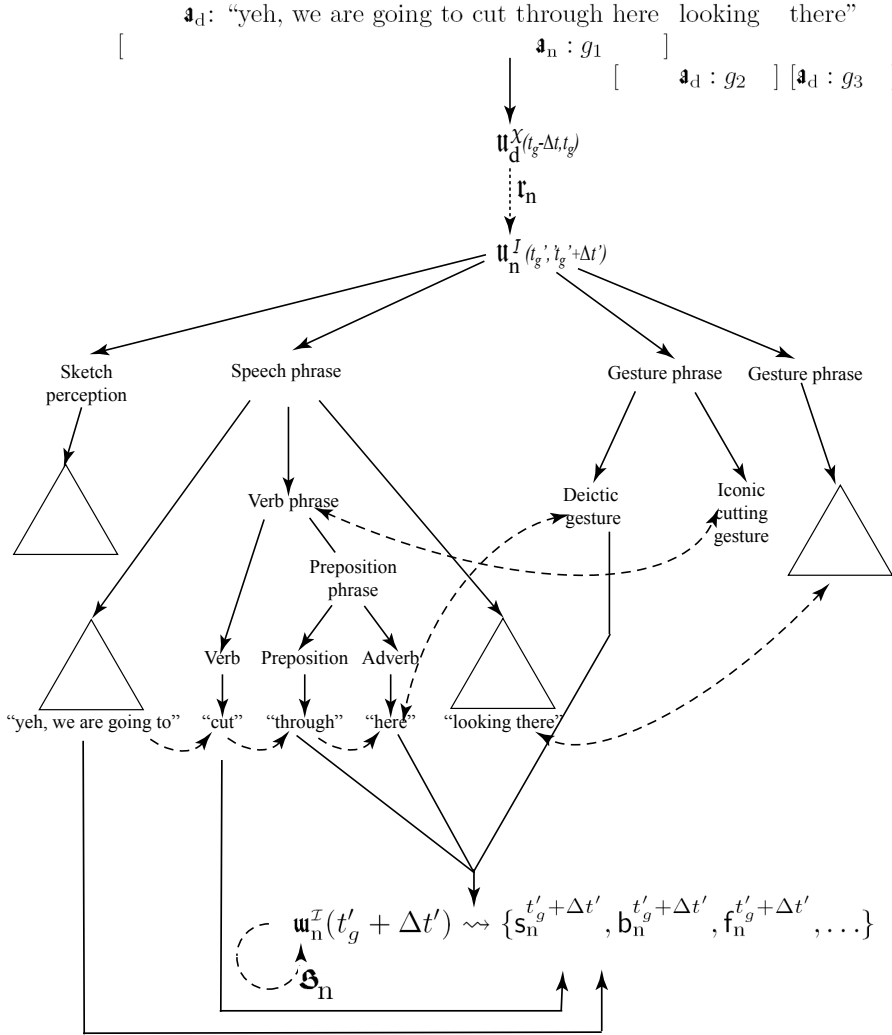


Fig. 6. Partial interpretation by  $\mathfrak{a}_n$  of communication by  $\mathfrak{a}_d$ . Dashed lines show dependencies. The dotted line labelled  $r_n$  indicates that direct and indirect communications by  $\mathfrak{a}_d$  to  $\mathfrak{a}_n$  are via the context of  $\mathfrak{a}_n$  and so rely on  $\mathfrak{a}_n$  receiving and interpreting them.

This example is included because it illustrates two ideas. The first is the importance of shared context to collaboration and the second is the use of direct and indirect communication across different modalities (speech, gesture, ...). Interpreting what  $\mathfrak{a}_d$  intends by a communication relies on much more than linking speech to gestures.  $\mathfrak{a}_n$  has existing interpretations  $u_n^I(t_g) \rightsquigarrow \{s_n^{t_g}, b_n^{t_g}, f_n^{t_g}, \dots\}$

that come from prior and current viewing and discussing the sketches and drawings to which they now gesture, previous sketches and drawings, domain knowledge, common ground and knowledge of what it is that they are currently designing. These all influence  $\mathfrak{a}_n$ 's current situation, changing how he behaves as a listener and so changing both of their contexts. It is the situation that directs  $\mathfrak{a}_n$ 's beliefs of what  $\mathfrak{a}_d$ 's intends by constructing a section through *atrium* and of what kinds of results to expect from it.

$\mathfrak{a}_d$  at  $t_g$  presumably has similar sense-data to  $\mathfrak{a}_n$  as they construct their contexts from the same part of the environment at the same time. Both look at the same sketches and drawings, hear similar words and noises, and so on. But at  $t_g$  when  $\mathfrak{a}_d$  starts sketching the new section, the situation as understood by  $\mathfrak{a}_n$  has him interpret what  $\mathfrak{a}_d$  is doing differently to how  $\mathfrak{a}_d$  interprets what  $\mathfrak{a}_d$  is doing - hence  $\mathfrak{a}_n$ 's "we should be going that way". The overlap of their contexts is large but  $\mathfrak{s}_d^{t_g} \neq \mathfrak{s}_n^{t_g}$  so even with identical sense-data their interpretations would be different. In this case they are sufficiently different that  $\mathfrak{a}_n$  and  $\mathfrak{a}_d$  think they are constructing different sections.  $\mathfrak{a}_d$ 's reply in speech and gesture is his trying to increase their common ground by describing what to him is the relevant part of his  $\mathfrak{u}_d^x(t_g)$ . The result for  $\mathfrak{a}_n$  is a changed interpretation  $\mathfrak{u}_n^x(t'_g + \Delta t')$ . The reason that the misunderstanding is corrected with so few actions by  $\mathfrak{a}_d$  is that most of the design is in the external representation and so is already in the shared context.  $\mathfrak{a}_d$  doesn't need to describe the new structure to  $\mathfrak{a}_n$ , he only has to shift  $\mathfrak{a}_n$ 's understanding of the situation enough for  $\mathfrak{a}_n$  to reinterpret it.

$\mathfrak{u}_n^x(t'_g + \Delta t')$  results in sense-data and percepts for the words shown in Figure 6, sense-data and percepts for the gestures shown in Figure 6, and sense-data and percepts for vision of the sketch that they are gesturing at. Interpreting the speech percepts moves from interpreting parts to wholes and interpreting the gestures moves from wholes to parts [29]. This is because words are received sequentially whereas gestures can be decomposed. The example speech contains a number of indexicals and as such depends on context  $\mathfrak{r}_n(t'_g + \Delta t')$  for an interpretation. Take the utterance "we" for example. If  $m$  is the speech shown in Figure 6 then the meaning of "we" is:

$$\begin{aligned} \exists x, y \bullet & x \text{ is the speaker of } m \wedge \\ & y \text{ are listeners of } m \wedge \\ & \text{the addressees of } m \text{ are } y \end{aligned}$$

The word "we" is indexical because its interpretation depends on the context but its abstract meaning can be understood without knowing to what  $x$  and  $y$  refer. An interpretation requires that these designate something, and this "what" comes from  $\mathfrak{r}_n(t'_g + \Delta t')$ . Given  $\mathfrak{u}_n^x(t'_g + \Delta t')$  and  $\mathfrak{s}_n^{t'_g + \Delta t'}$ ,  $x$  is fixed as referring to  $\mathfrak{a}_d$  and  $y$  is fixed as referring to  $\mathfrak{a}_n$ . That is, "meaning determines content relative to contextual factors" [30]. There is also more going on here

than interpreting indexical and non-indexical words. A listener is not completely passive in a communication: body position, movement and non-verbal sounds signal interest, understanding, agreement and so on to the speaker [31]. The gestures are “co-expressive” and synchronous with speech, but they are not redundant [29]. Interpreting the word “here” is a clear example. It too is an indexical but of a particular kind called a “demonstrative” [30]. The word “we” is indexical but the context is sufficient to fix the referents of  $x$  and  $y$ . What the word “here” refers to cannot be determined without a demonstration - in this case  $\mathfrak{A}_d$ 's deictic pointing gesture  $g_2$ . Interpreting what  $\mathfrak{A}_d$  intends by “here” requires interpreting and linking speech and gestures in the same context.

The examples described in Section 3 illustrate the vital distinction between context and situations. Sketching over an old drawing is a case where the context provided by the old drawing is vital to the kinds of design sketching actions that are generated, but it is the situation that makes it the context and that drives interpretation and consequently how that context and those actions are interpreted. When  $\mathfrak{A}_d$  discovers the angled bridge it is because he is concurrently acting on and perceiving an external representation of the developing design. He synthesises a potential design action and performs a repeated design experiments by repeatedly sketching and interpreting that external representation. Common ground is essential to communication but we can understand it better when we consider it in terms of situations and shared contexts. Indexicals and gestures pervade the design session and we can understand them directly by considering their role in agents altering how others interpret their shared context.

## 4 Conclusion

We described the external world of an agent as an aggregation of entities that an agent could sense or effect, with context being from those processes of its external world that it interacts with and is aware of. The interpreted world of an agent was described in terms of the experiences of that agent, with situations being processes that direct how interactive experiences proceed. Situations determine what external processes are in the current context, and situations influence interaction and so influence what and how common ground is acquired. Even though the term “context” is widely used, by itself it doesn't make sense without understanding what situations are and what role they play. Common ground is essential for communication but as it arises within an agent, it can be explained readily due to the distinction we have drawn between situations and contexts. This distinction between situations and contexts has the potential to provide a means to address a number of related issues that include interpretation and creativity, however, explorations of these issues will

be left to a future paper.

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