Reasoning About Interactive Systems in Dynamic Situations of Use

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Abstract Interactive software, systems and devices are typically designed for a specific (set of) purpose(s) and the design process used ensures that they will perform satisfactorily when used as specified. In many cases users will use these systems in unintended and unexpected ways where it seems appropriate, which can lead to problems as the differing usage situations have unintended effects on use. We have previously introduced a method of combining formal models of interactive systems with models of usage scenarios to allow reasoning about the effects that this unintended use may have. We now extend this approach to consider how such models might be used when considering deliberately extending the usage scenarios of existing interactive systems to support other activities, for example in emergency situations. This chapter explores a methodology to identify the effect of properties of emergency scenarios on the interactivity of interactive systems and devices. This then enables us to consider when, and how, we might utilise such devices in such emergencies.

1 Introduction

Interactive systems are typically designed around a specific set of use-cases (and in some cases particular users) to ensure that they will fulfill the needs of the *intended* users for the *intended* use. As part of this design process, issues of usability will also be addressed, and if the environment in which the system will be used is itself challenging (which is increasingly common), then this must also be included in the usability evaluations and user studies. While the established, and well-studied techniques of user-centered design, HCI or UX, will be successful in ensuring the

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systems are appropriate for their *intended* use, it is not always the case that systems will be used as intended. It is well-known that users will often interact with systems in unexpected ways, but what we consider here is use in entirely different contexts than those for which the systems have been designed. There has, of course, been much research into context-aware and adaptive systems, which includes considerations of context-of-use, but here we address the problem of non-context-aware systems being used in different contexts than those they were designed for.

If systems are used outside of their designed-for context, there may be unexpected or unintended consequences. These might be considered as merely annoying to a user. However, if the system in question is safety-critical, and the user is unaware of limitations that may occur due to a different usage situation then more serious consequences may result. Our original work in this area was motivated by exactly such a problem in healthcare environments. Medical devices, such as syringe and infusion pumps designed to be used in hospital wards or palliative care facilities, were being used in more challenging environments (emergency rescue helicopters, in-situ accident response etc.) which could lead to problems with proper use.

Our focus on this problem led us to develop a modelling approach that allowed for reasoning about the effects of using interactive systems in different contexts of use. Specifically when the system itself is not context-aware or adaptive and it is up to the user to understand how and why they may need to adapt their behaviour to successfully interact with the system. In this chapter we extend this approach to consider the deliberate appropriation of interactive systems for use outside of their designed-for context.

We first give an overview of some of the motivations for this work and outline the types of scenarios that are of interest. We focus specifically on the example of using existing large-scale information displays out-of-context in situations of emergency. We first explore the information needs that arise in such situations. Emergencies such as earth quakes, floods or simple electricity cuts create unexpected information needs. During a conference stay, one of the authors found themselves stuck on the 6th floor of a darkened hotel without electricity. Established means of communication had ceased to function (phone, WiFi) and emergency lights were not working. A huge billboard opposite the hotel was clearly visible but did not provide any helpful information. This chapter is about using available means of communication, such as the large-screen billboard, in non-standard ways in case of emergency.

ICT is widely used in emergency situations. It has been observed, however, that social and organisational concerns often go beyond the available ICT support and even emergency-specific technological solutions and systems are abandoned (Bodeau et al, 2010). Emergency logistics and communication needs are unpredictable and may involve a number of government, private-sector or NGO agencies, local first responders, and ad-hoc groups of citizens in addition to affected people in a disaster area. Brooks observed that the interdependent flow of information and control “cannot be easily disentangled” nor planned ahead precisely (Bodeau et al, 2010). Although information need and control flow between external agencies has been recognised as being complex, involving subgroups and dynamic cliques (Comfort and Haase, 2006), we consider all of these parties as

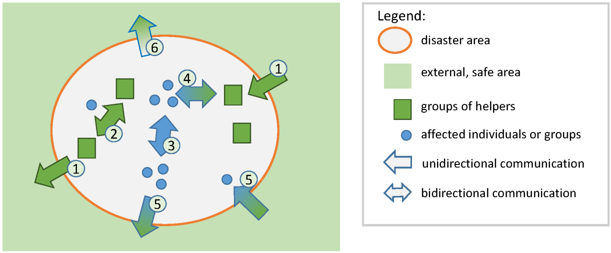

Fig. 1: Types of communication and information flow: between external management, responders, affected individuals, and from the disaster area via sensors

a transparent external body and abstract from the flow of control and information *within* this response agency.

Management of complex situations such as natural disasters, flooding, forest fires, earth quakes and mass-casualty accidents often leads to communication breakdown and information loss (Parush and Ma, 2012). Good situational awareness is vital for decision making and quick response (Yang et al, 2013). A number of studies have analysed the information requirements of emergency response teams, e.g., (Diehl et al, 2005; Robillard and Sambrook, 2008; Yang et al, 2013). Extreme importance is given to information about environmental conditions in an intervention as well as to response participants, status of casualties and available resources. These are to be obtained from local people, on-site personnel and sensors in the incidence area.

We can conclude that whilst categories of information needs may be predicable, detailed requirements will not be and suitability of locations will depend on the given context. Figure 1 gives an overview of parties involved and communication channels: Emergency management is typically located outside the disaster area, with groups of helpers entering the area in which groups or single individuals may be situated. Communication is needed ① between management and responders, ② between groups of responders, ③ between affected individuals, as well as ④ between individuals and responders and ⑤ directly between individuals and management if possible. Finally, emergency management may be able to obtain environmental information directly from sensors ⑥. The two main types of communication are information collection for emergency management and provision of information to the individuals in affected areas, using various channels. Some channels may allow two-way communication, others work only uni-directional. Here we are concerned predominantly with communication channels ③, ④, ⑤ and ⑥, which are those that cannot rely on specialised or specifically provided communication technology (as ① and ② can).

In case of emergency, all available communication channels need to be used. Traditional emergency communications delivered via a central communication channel is to known recipients and relies on specific hardware with the individual (radio, phone etc). If we want to exploit any existing technology in a vicinity we need some way of managing the information about its capabilities and its limitations under certain circumstances. Because traditional mechanisms of communication may be interrupted by a disaster (e.g. phone networks) having the ability to provide large-scale communication in other ways may be important. In-situ large screen displays are potential communication media. It is conceivable that in-situ displays can also be used to gather information and send it back to a central point. We explore this further in Section 4.

In this chapter we describe a modelling approach to explore the use of large-screen displays for emergency communication. Section 2 gives an overview of how we have used this modelling approach to support interactive medical devices in different contexts of use. We then go on in Section 3 to show how this can be applied to understanding how public interactive displays (such as those described in case study 3) might be used in emergency situations. Section 4 explores a larger example from the area of emergency communication. In Section 5 we compare our approach with those from related work, and conclude this chapter with a summary in Section 6.

2 Background

In earlier work we investigated ways of modelling the interactions of a system or device to understand how it might be compromised when used in particular situations where environmental factors could interfere with normal methods of interaction (Bowen and Hinze, 2012). The intention was to be able to inform users about these compromises so that they could adapt their use (so here the user becomes context-aware and adaptive rather than the system) in order to successfully use the system differently. By creating models of interactive systems and their widgets, and characterising these by their interaction types (which in the broadest sense can be described as visual, audible, tactile etc.) we could then create relations to models of locations and limiting factors which subsequently enabled reasoning about the effects of these limiting factors.

This approach allows us to answer the following sorts of questions about interactive systems (S and T) in various situations of use (L and M):

- Can S be used in L?
- Is it better to use S or T in L?
- What does the user need to be aware of when using S in L?
- If L becomes M what affect does this have on S?

The answers can then be used to inform users and allow them to make decisions about which devices to use when, or to understand that how they use the device or system may need to change.

We start with an initial model of the interactive system which describes the interaction possibilities in terms of the widgets the system has (buttons, menus, displays *etc.*) and the categories, or types of these widgets which informs the *nature* of the interaction. For example, a button which requires touch for interaction can be labelled as haptic, whereas an alarm which sounds in a given condition would be categorised as audible. These are lightweight descriptions which aim to capture the essential elements only, so we do not describe the low-level descriptions of physical characteristics of widgets seen in chap. 9 for example. The interaction information from this model is then combined with a model of a given situation of use, which are properties of different situations relating to environmental attributes (such as noise and lighting levels), tangible properties (which for our previous work in the medical domain were things like patient/practitioner ratios), as well as less tangible attributes such as the levels of stress experienced by users in a given location.

The models consist of descriptions and relations, and as such can be expressed, and reasoned about using a variety of formalisms or notations. From the interaction and location properties we create a relationship between types of interaction and location attributes where the interaction would be adversely affected. For example an audible widget (such as an alarm) would be adversely affected by a noisy environment (as the alarm might not be heard). Previously we showed how ontologies could be used for the purpose of describing the interaction properties and location factors and for creating the relations between them (Bowen and Hinze, 2012). We then used the semantic web reasoning language, SWRL (Horrocks et al, 2004a) within the ontology tool Protégé (Gennari et al, 2002) to generate classes of affected devices in given locations. Subsequently we incorporated the reasoning into a tool which provides the relevant information (i.e. the answers to the questions listed above) in a palatable form for users (Bowen et al, 2014).

The four questions listed above were originally developed from the requirements of using medical devices outside of their intended usage scenario (for example when a syringe pump designed to be used in a medical ward is taken into an emergency rescue helicopter). However, these questions are equally applicable in other domains (for example when Department of Conservation workers need to use field equipment in new environments) and for other purposes (determining which equipment is most suitable to be placed in-situ in an environment which has changing conditions). Here we show how we can use the same approach to support dynamic reasoning about interactive systems in emergency situations in order to support emergency management scenarios. We are still focused on the problem of non-context aware (and non adaptive) interactive systems. However, rather than using the models to determine how a user's interaction may have to change when using a particular device in a different location, we consider how we might take advantage of in-situ devices (such as large-screen interactive public displays) in emergency situations by reasoning about the available interactions, given some environmental properties which result from that emergency. The information we are modelling remains the same, but the reasoning we perform and the intended results are different. As such we have a fifth question which we wish to answer (and so add to the list above), given a collection of interactive systems $S^{1..n}$ in a location L, and a use-case U, in an emergency situation E :

- Which of $S^{1..n}$ in L can satisfy U in E?

One of the differences here is that we are now considering situations where the situational factors are not fixed, but rather occur due to some event and may change over time. However, the ability to reason about their effect remains the same, albeit more dynamic, and so we extend our approach to incorporate this. We will still have models of the interactive systems and their widget types, but in this case the models will be for all interactive systems we know about in a given geographical location that we can utilise for some form of emergency management or communications. The reasoning rules will allow us to reason about what type of event attributes impact particular types of interaction – and therefore particular interactive systems in the domain. These will be used in conjunction with dynamic models of actual effects of an event as it occurs. We give details of this next.

3 Models and Reasoning

We create models for each of the information types involved in the reasoning. The first are the sets of properties of the interactive systems and devices which are known to exist in a given location. For our previous work with safety critical medical devices we typically already had initial models (based on the presentation models of (Bowen and Reeves, 2008)) from which we could automatically extract widget and interaction information. As the interactive systems we are now dealing with are not safety critical, this is less likely to be the case and so we manually create the sets of properties of interest. These are the *types* of interactions the widgets of the system provide. The second model describes the relationships between interaction types and *all* known possible effects that may result from an emergency event. In their simplest form these can be characterised as a binary relation where a *factor* affects a *widget type*, such as *noise* affects *audible* for example. However, in practice the range of properties and effects are much more complex and include variable attributes (actual decibel levels of noise volume perhaps where the level affects different types of audible output). In this section we primarily focus on binary relations as we describe the approach generally, and we will expand on these to show more complex relationships in Section 4 where we present a larger example.

We consider every possible effect that may hinder a particular type of interaction as the basis to build the relation used in the reasoning. The interaction types of the systems and the effect relation are considered to be ‘fixed’ models, in that they can be created ahead of time and describe the things we already know and which do not change. Then there is a dynamic model which is created when an event occurs. This contains only the event factors which are relevant in the given scenario, i.e. result from the event. It is these dynamic factors that are used to reason about the availability of both interactive systems, and their interactive capabilities in the given emergency situation. The final description generated from the reasoning is a subset of devices containing a subset of their interactive capabilities, which can then be used to make decisions about which to use for any given use-case. That is, we choose from this subset of systems based on which still have the required interactions available for our needs.

There are many different ways of describing the models and reasoning about them (Bowen et al, 2014). Here, we describe the attributes and properties as sets to show the effects of the relations, but we can practically implement the reasoning described in several different ways, including following the ontology approach used previously. This is particularly useful for automatic reasoning on multi-faceted attributes with more complex relations, such as those we will present in our larger example.

The large interactive displays described in the case study are typical of the types of systems we may wish to exploit for information provision or data gathering in an emergency scenario. Suppose that both the Domain Mall Interactive Display and the Magic Carpet are located in an area we wish to incorporate into our emergency planning scenario (a large shopping mall for example). We can create initial fixed models for their interactivity (which we separate into input and output interactions) as follows:

Magic Carpet INPUT = {Touch}
Magic Carpet OUTPUT = {Visual, Audible}

Domain Mall Display INPUT = {Motion, Location}
Domain Mall Display OUTPUT = {Audible}

The full set of interactions for each of these systems is then the union of their input and output sets. The set of all possible interactions for any given collection of devices in a domain is the union of their respective interaction sets.

The second fixed model is the relation of effects to interaction types (e.g. Noise $\mapsto$ Audible). We have a set of all known situational factors, and create a many-to-many relation between this and the set of interactions. Given the example systems above, and an assumed set of factors we can describe the following:

INTERACTIONS = {Touch, Visual, Audible, Motion, Location}
FACTORS = {Noise, Heat, Vibration }
EFFECTS = {Noise $\mapsto$ Audible, Heat $\mapsto$ Touch }

This is an example of the simplest type of relation, the binary relation where a named factor affects an interaction. However, in real-world scenarios the effects are typically multi-faceted, as we will see later in our larger example. The dynamic model of scenario factors is generated in a given emergency situation. Suppose we have a bomb-warning in a public area which has led to the sounding of the evacuation alarms, from this we can determine that for this scenario:

FACTORS = {Noise}

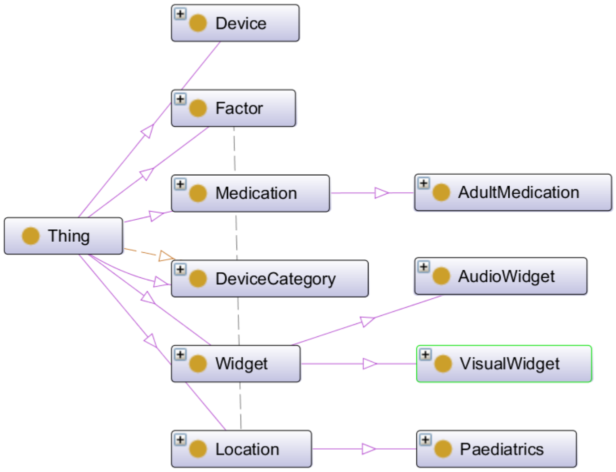

Fig. 2: Example of the ontology hierarchy

Our emergency management requirements for this scenario are to provide additional information to assist with the safe evacuation of people by directing them to particular exits and keeping them away from specific areas of the building. We therefore only need to consider the available output interactions. We take the set of known factors and restrict it to create the *current effects* relation (a subset of the elements in effects) using the dynamic event factors. So here we now have $\{\text{Noise} \mapsto \text{Audible}\}$. We then retrieve all interactions in the relation for these factors ($\{\text{Audible}\}$) and remove these affected interaction(s) from the interaction set of each device to gain an overview of remaining interactive availability, that is, the complement of affected interactions with respect to interactions:

$$\begin{aligned}&\text{AVAILABLE\_INTERACTIONS} =\\ &\quad \text{INTERACTIONS} \setminus \text{AFFECTED\_INTERACTIONS}\end{aligned}$$

If the result is the emptyset, $\emptyset$, there are no available interactions remaining for a system and we cannot use it in the given scenario. If the remaining interactions are a subset of total interactions then we can use the system in a restricted capacity, otherwise we can use it fully.

For this example then, the remaining interactions for the Domain Mall Display and Magic Carpet would be:

$$\begin{aligned}&\text{Domain Mall Display} = \{\text{Visual, Audible}\} \setminus \{\text{Audible}\} = \{\text{Visual}\}\\ &\text{Magic Carpet} = \{\text{Visual}\} \setminus \{\text{Audible}\} = \{\text{Visual}\}\end{aligned}$$

So we can use both of these devices, but the Domain Mall Display only in a limited capacity to display information.

In order to support automated reasoning about more complex scenarios and factors we have shown previously how we can model these relationships in an ontology using the Protégé tool (Gennari et al, 2002). Figure 2 shows a snippet of the class hierarchy for the medical device example. The members of "WidgetsRestrictedByEvent" are populated by the first level of reasoning using rules such as:

```
Widget(?w),
hasfactor(Event, ?f),
restrictsWidget(?f, ?w)
->WidgetsRestrictedByEvent
```

So, if an event has a factor that restricts a widget, then that widget is categorised by the reasoner as one of the widgets restricted by that event based on their interaction type. Similarly we can create categories for systems affected by events (those which have widgets in the affected category) and so on, to expand the descriptions and generate the required information. When an event occurs we use the effects it has as parameters to the reasoning rules.

Typically the sets of interactions and event factors will be larger and more complex than the simplistic values given above. Noise, for example, can be considered at a more granular level within certain ranges of volume. We want to incorporate this richness in order to be more precise about not only the details of the factors, but also the detail of the interactions. So rather than just considering how the system can be interacted with in terms of its categorisation, we also include details of what *types* of information are associated with these interactive categories.

The Domain Mall Display for example has different types of visual outputs it can display – images, text etc. Other systems, such as interactive maps, may be more limited, while others may have a larger range of capacities. It may be the case that only some of these are affected by different levels of event effects and so all of the models need to be expanded to incorporate this. These multi-faceted attributes can also be considered within an ontology. We can then use the same approach by modelling the event factors as objects with multiple facets of interest and extend the widget interactions to include detail around types of information. A more realistic set of factors, interactions and effects, therefore, is shown in the larger example in the next section.

4 Earthquake Emergency Management Example

We expand on our basic theory to describe how we can use this approach with more complex interactive systems in scenarios with a variety of more interesting properties. The example situation is that of an earthquake, with affected areas being those found in a typical urban setting, e.g., shopping malls, living quarters, train stations, central business district (CBD), indoor and outdoor amusement parks.

(a) Train Station (b) In-Train Display

(c) Public Display (d) Large-screen Advertisement

Fig. 3: Large-screen public displays

Communication in Earthquake Emergency

The types of large-scale displays one would encounter in such areas range from simple moving LED displays to announce the arrival of the next train (see Figs. 3a and b), interactive urban information screens (e.g., displaying maps and local information as in Fig. 3c (Kostakos et al, 2012)), dynamic advertisement screens (Fig. 3d), media facades (Köster et al, 2015), multi-screen displays, sensor-equipped screens for environmental monitoring, to interactive art installations (e.g., using Sensacell technique[1] or using cameras, sensors and motion controllers (Fortin et al, 2013)). Interactive large-scale displays can capture input from motion (proximity sensor) and touch (touch screen elements) and provide output visually via the display or audibly via speakers.

In case of emergency, we may want to use screens and displays differently from their ordinary usage pattern. Some behaviours that are built-in (e.g. the response to inputs in normal usage) might be usefully employed in an adapted manner. Others might need to be used in a radically different way to their original design intention (e.g., for providing illumination or giving directions). The emergency usage scenario does not contain pre-defined event effects as our previous medical example

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[1] www.sensacell.com

did (see Section 2), rather the situation needs to be evaluated as it develops. For each scenario, the applicable effects need to be identified and it then needs to be reasoned which elements of the displays can or cannot be used due to restrictions.

In the aftermath of an earthquake, there will be increased risk of collapsing buildings, landslides during rain, and liquefaction.[2] Communication tasks for such an example that could be supported via the large-scale displays would be:

- Inform: Rescuers might wish to inform people in the emergency area about the situation, and warn about potential aftershocks (using text, images, audio).
- Direct: Directions may need be given to both first-response rescuers as well as affected people. Examples are directions *towards* meeting points, safe areas, medical help, or *away* from dangerous areas (using text information, maps or arrows, possibly via several screens).
- Warn: Warnings about localised danger of collapsing buildings or areas of liquefaction (so-called red zone), or about dangerous volatile substances such as carbon monoxide risk or chemical hazards (e.g., via images, voice or alarm sound).
- Interact: To gain an overview of the situation, rescuers may wish to identify how many people are located in a restricted area and their particular needs (e.g., medical)
- Measure: Any sensors on a display may be employed to gain further information about the local situation: stability of the ground, level of chemicals, heat, etc.

Not all displays can equally support all activities and interactions. For example, the communication via displays may further be hindered by hazards that affect the visibility, such as darkness, dust, steam, glare, (partially) broken display and accessible distance to display. Audio signals may have to be used in addition to other information or on their own. Audio signals may be impaired by environmental noise before or during the earthquake (so-called artillery-like ‘earthquake booms’[3]) and after (e.g., from collapsing buildings or broken pipes) or obscured by broken speakers. The earthquake survivors might be injured, disoriented, alone or in groups, trapped inside or outside. They may be locals or tourists, with or without knowledge of the location, or local language, mobile or impaired. We now describe a selection of specific situations and their communication needs. Based on the types of communication tasks described above and the situations that helpers and affected individuals might find themselves during an earthquake, the following communication tasks may arise.

Directing people towards medical help: Groups of affected individuals may be situated in, or move through, the disaster area, many of which may need medical help. One of the first responses is to set up medical emergency centres and to announce their locations to people in the affected areas. During the initial phase of medical response (moving from so-called solo treatment areas to disaster-medical-aid centres), traditional communication relied on runners (Schultz et al, 1996). The location of treatment areas and (once these have been established) the locations of

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[2] Liquefaction is a process in which during an earthquake soil is rearranged such that it behaves more like a liquid than a solid.

[3] http://earthquake.usgs.gov/learn/topics/booms.php

medical-aid centres need to be made known to affected individuals. The communication of dedicated locations may use one, or several, of a variety of location indicators, such as the name of a place or its address. These, however, may only be useful for people with local knowledge. Better location indicators may be widely-visible landmarks, maps, signs and arrows, accompanied by simple indications of distance. LED-based displays (such as the ones shown in Figure 3a and b) could be used to display text (such as name, address, distance) and simple signs (e.g., arrows), but could not serve complex maps. Using directional arrows relies on clear positioning information of the display and may be liable to repositioning due to damage. Information screens, advertisement or media facades (see Figure 3 c to f) can serve text, signs and complex maps. Directional arrows are safer to use on stationary facades as smaller displays may have been dislocated.

Warning about danger area: Some areas may be dangerous to enter after an earthquake, for example, large or overhanging buildings that are in danger of collapsing, or areas in which the ground is unstable. Signage directly affixed to buildings or near these areas can be used to prevent people from entering. Communication via screens or facades (see Figure 3c to f) may use warning signs, images, videos and text, with possible use of additional audio warnings. Displays in close proximity to the area would need to name the location, and use maps and signs. As with directing people, warnings using LED are restricted to text and simple signs with possible warning audio.

Interacting with people in a location: In order to gain intelligence about the emergency situation on the ground, and about the people affected, interaction with individuals that are located in the emergency area is crucial. Interaction may be directly via screens that have input options (such as urban information screens and art installations, see Fig. 3c and Fig. 3e+f, respectively), or indirectly by alerting people to available communication channels. For example, LED screens, advertisements and media facades may show emergency telephone numbers or social media contacts. Screens with interaction capabilities may be used depending on the supported functionality, such as microphones, cameras and touch screens.

Other communication goals may be the interaction with people in enclosed spaces (inside collapsed building), coordination of numerous groups of first response helpers, and provision of general information about the situation (equivalent to using the billboard to provide information to people in a hotel without electricity).

Modelling of Earthquake Example

The nature of the data we model for both interactive systems and event effects is now extended to consider more specific attributes as well as valued-attributes. Figure 4 shows how these can be used to build up more complex relations than the previous binary examples. It is no longer the case that an event effect simply restricts a type of interaction. The level of the effect (e.g. decibel level for noise) affects a particular type of interaction data of a system. So rather than just considering an output interaction to be ‘visual’ we use a more finely-grained description which considers more detail of the interaction (not just how it occurs) which might include items such as text, images, voice audio, alarm audio etc. The relation then is more specific being between levels of effects and defined items of interaction data.

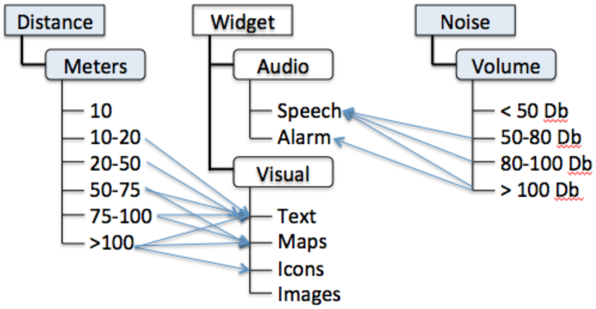

Fig. 4: More detailed relation of effects on interaction data types

When we want to decide which of the public displays in our emergency communication area are available for us to use, we also need to identify the type of information we wish to communicate (so again we aim to answer the question “which system is the best to use for this scenario?”) We also want to find out which (if any) of the available systems can provide this feature in the current event. For example, if the location of the Media Facade has obstructions on the ground which prevent people getting closer to it than 50m, then it is not useful for displaying detailed text instructions as people cannot get close enough to read them. We can, however, use it to display images (which might include standard emergency representations such as a red cross to indicate medical facilities or a no entry sign) or simpler, easily-recognised icons such as those shown in Figure 5 for way-finding or access control.

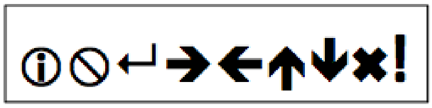

Fig. 5: Icons

These can be viewed, recognised and identified from further away, and so will be affected by different values of the event attribute. Legibility of public displays is an important consideration, especially when being used in emergency scenarios. Work by Xie et al. (Xie et al, 2007) has proposed methods to model and validate sign visibility during design and prototyping phases and we can imagine incorporating the data produced by such a modelling process into our effects relation.

The full data we must now encapsulate in our models includes:

- Interaction sets for all interactive systems available in a given geographical area
- Data types of the interaction sets
- Event effects, and attribute values
- Requirements of data we wish to collect or output to manage the event

In the earthquake scenario described above, we have access to the following devices and interactions in the geographic location of interest:

LED Display INPUTS = {}
LED Display OUTPUTS = {Text, Icons, Numbers}
Info Display INPUTs = {Touch}
Info Display OUTPUTS =
  {Text, Icons, Numbers, Maps, Images, VoiceAudio, Alarm}
Media Facade INPUTS = {}
Media Facade OUTPUTS = {Images, VoiceAudio}

As we are able to gather information about the event and its effects in the given location we can begin to reason about the interactive systems and their available interactions in the manner described in Section 3. Now, however, we reason about the effects at a per system level, rather than for all systems, as the particular effect attributes and their values may differ from system to system depending on their location. We map the effect to the system based on precise geographical co-ordinates.

Our requirements are to provide information in the form of maps, text and icons to indicate location of medical services, whilst at the same time trying to gather information about the number of people in the geographical area. Our goal is to identify which (if any) of the public displays can be used to display any or all of these types of data (which have visual capacity for these items in this event scenario) and which (if any) can be used to gather data from people (can both display textual instructions and accept touch inputs which can be used as a simple counting system).

The general environmental factors of the earthquake in the specified location are noise, unstable ground, dust, obstructions and unsafe buildings. The particular effects for each of the interactive displays we are considering are expressed at the more detailed levels for the known parameters as we can identify them. For example ground obstructions in front of a display are expressed in terms of estimated distance.

LED Display location effects = {Noise[>100 Db], Distance[>30m]}
Info Display location effects = {Noise[30-50 Db], LightLevels[dark]}
Media Facade location effects = {Noise[50-75 Db], Vibration }

This allows us to generate the sets and types of available interactions for each of the displays and then co-ordinate our information provision on a best-fit basis. Using a valued-relation, such as that shown in Figure 4 we can now reason about these effects. The resulting available interaction sets are generated by removing the affected interactions based on the current effects relation:

LED Display AFFECTED_INTERACTIONS =
{Text, Numbers, Maps, VoiceAudio, Alarm }
Info Display AFFECTED_INTERACTIONS = {VoiceAudio}
Media Facade AFFECTED_INTERACTIONS = {VoiceAudio}
LED Display AVAILABLE_INPUTS = {}
LED Display AVAILABLE_OUTPUTS = {Icons}
Info Display AVAILABLE_INPUTS = {Touch}
Info Display AVAILABLE_OUTPUTS =
{Text, Icons, Numbers, Maps, Images, Alarm}
Media Facade AVAILABLE_INPUTS = {}
Media Facade AVAILABLE_OUTPUTS = {Images}

Finally we consider again the requirements we have for this emergency situation, which are to provide information in the form of maps, text and icons as well as gathering input using touch. From the restricted sets of interactions we see that we can use the Info Display to gather information, and all three of the devices can be used to provide information but with limitations on which types of information they can display. Over time the event effects may change, for example the noise level in the LED Display location may drop to below 50Db, when we become aware of the changes we can recalculate the effects and change our information provision as required.

We can use our previous approach of an ontology and reasoner to describe these properties and infer the information shown above. We have been using the Protégé (Gennari et al, 2002) tool to build ontologies using the OWL ontology language[4]. This type of ontology consists of classes, individuals (or instances) and properties.

We create two classes initially, *InteractiveDevices* which has three instances (*InfoDisplay, MediaFacade* and *LEDDisplay*) and *InteractionType* with eight instances (*Out_Alarm, Out_Images, Out_Maps, Out_Numbers, Out_Icons, Out_Text, In_Touch* and *Out_VoiceAudio*). Properties are binary relations on individuals and we use two different types of property. First, an object property (which relates individuals) called *hasInteractionType* which relates instances of the *InteractionType* class to instances of *InteractiveDevices*, e.g. LEDDisplay *hasInteractionType* Out_Text. We also create the inverse of this property *InteractionTypeOf* and the ontology reasoner automatically populates this relation. We then create datatype properties (which relates individuals to data literals) for the valued properties: *hasNoiseLevel, hasDistanceFrom, hasLightLevel* etc. and populate this with the individual instance values for this scenario, e.g. MediaFacade hasNoiseLevel “>= 50”. Figure 6 shows the visualisation of the classes and relations.

Once we have added all of the known data to the ontology (which consists of both the pre-known device data as well as the current scenario data) we can create ad-

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[4] `http://www.w3.org/TR/owl-guide`

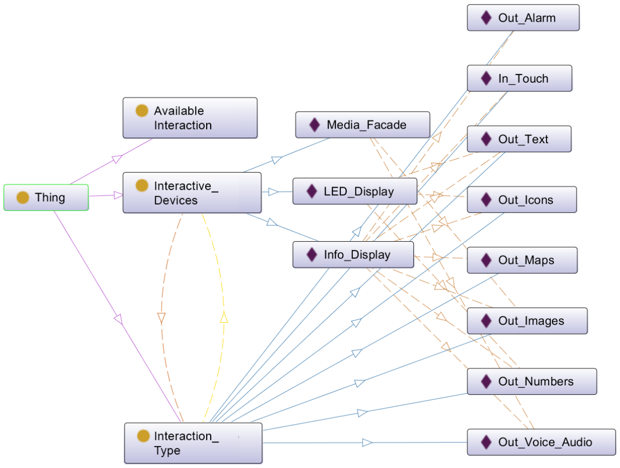


Fig. 6: Ontology structure for earthquake example

ditional classes, *AffectedInteractions, AvailableLEDDisplayInteractions* etc. which will provide the dynamically generated results from the SWRL reasoning.

An example rule is shown below, describing the pattern to identify all devices with output affected by noise levels of more than 100db.

```
Interactive_Devices(?device),
Interaction_Type(?output),
hasInteractionType(?device, ?output),
hasNoiseVolume(?device, ?noise),
greaterThan(?noise, 100),
SameAs(?device, LED_Display)
-> hasAffectedOutput(?device, ?output)
```

4.1 Use in Practice

As previously stated, while we can use Protégé in this way to support the modelling and reasoning via an ontology, this is not a practical approach for non-expert use. In order to solve this problem we use the ontology data as the input to a custom-built tool which provides an easy-to-use front-end. This enables a user to pose specific questions such as “Can I use this device in this situation?” and provides relevant information to support their choice. Figure 7 gives an overview of the components for such a tool. The ontology is built using the information from the device models and rules generated by the domain experts. The data from the ontology then provides the basis for the end-user tool. A second tool can be used to update the ontology if new data emerges during the emergency scenario allowing the reasoning to remain dynamic.

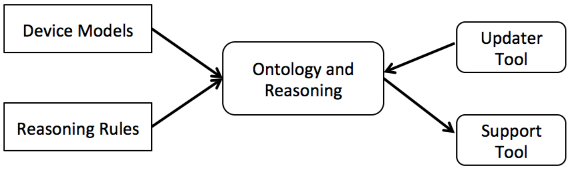
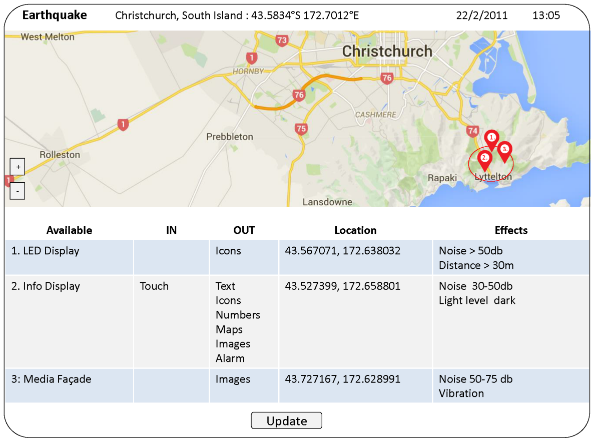


Fig. 7: Overview of tool structure

Such a tool must be tailored to the specific end-user and their requirements – for example a local government emergency management body. We have previously developed such a tool for use with our medical domain example (Bowen et al, 2014) and suggest using the same approach to develop a tool for the emergency management scenarios.

Figure 8 shows a proposed prototype interface for such a tool. An interactive map allows the user to navigate to selected areas within the disaster zone and this shows the public displays that are available in that area. These are then listed with their available interactions to enable decisions to be made about which can be used for different communication requirements. The current effects of the situation and their locations are also shown. Clicking the ‘Update’ button allows the user to add or edit location effects enabling dynamic reasoning as the situation changes over time.



Earthquake Christchurch, South Island : 43.5834°S 172.7012°E 22/2/2011 13:05

Available	IN	OUT	Location	Effects
1. LED Display		Icons	43.567071, 172.638032	Noise > 50db Distance > 30m
2. Info Display	Touch	Text Icons Numbers Maps Images Alarm	43.527399, 172.658801	Noise 30-50db Light level dark
3: Media Façade		Images	43.727167, 172.628991	Noise 50-75 db Vibration

Fig. 8: Prototype of End-User Tool

So now, to find the answer to the question posed earlier: given a collection of interactive systems $S^{1..n}$ in a location L, and a use-case U, in an emergency situation E :

- Which of $S^{1..n}$ in L can satisfy U in E?

we can use such a tool. In the prototype of Figure 8, each interactive system (S) is listed along with its location (L) and the available interactions in the emergency situation (E) to show which can be used to meet the use-case (U).

5 Related Work

We outline here related work on disaster management communications and information provision using large-scale public displays as well as on semantic modelling for interactive and context-aware systems.

5.1 Disaster management and communications

Much of the research focussing on the use of technology in disaster management and communication relates to one of two things. Firstly there are approaches which consider how existing large-scale technological solutions can be used to gather, disseminate, and manage information in emergency situations. This may include things like the use of social media and how shared information can be mined and utilised in uncertain conditions (Lu and Yang, 2011) or the use of in-situ technologies built on data gathering from RFID or sensor technologies communication via ad-hoc wireless networks (Yang et al, 2009). Secondly are approaches which look to create better centralised views of disasters for control centres through approaches such as interactive mapping and two-way communications via, for example, smartphones. An example of this can be seen in (Schöning et al, 2008) where smartphones are used as augmented reality devices through combining cameras and paper maps to relay spatial information.

Large shared physical displays and pinboards have a long tradition, for example for fire-fighter support (Jiang et al, 2004). Increasingly, social media is used as auxiliary media type in disaster response (Yates and Paquette, 2011; Horita et al, 2015) for communication between affected citizens, helpers and response agency, typically in an ad-hoc fashion. Current use of displays in public places is typically targeted to serve for advertisements, traffic information, or as elements of public art. The latest models of large-scale displays can now be used for delivering multimedia content and are context-aware (i.e., using sensor input to deliver content-specific content) (Davies et al, 2014). To remedy the lack of information, the use of large-scale displays has been explored in (Olech et al, 2012). To avoid lost time when searching for the best route to a site, or for coordinating first responders, they propose an interactive pinboard. Public screens being used as digital pinboards had previously been used for artistic purposes or social communication (Cheok et al, 2007; Hosio et al, 2010; Thelen et al, 2010). Interactive public displays are used to broadcast information (i.e. as digital signage playing video, animation, photographs) or interactively. (Ojala et al, 2012) explored the use of interactive features and found that beyond maps and consumer information, services were often unexpectedly popular or unpopular and not in keeping with previously stated information needs. They discovered that location is a major factor for the success of a service. These displays were placed purposefully and did not re-use in-situ hardware.

The use of such pre-existing technology available in-situ for signage and communication in emergency situations has been little explored. For example, (Majumder and Sajadi, 2013) mentions the option of using large displays for emergency response without giving further details. Both (Rauschert et al, 2002) and (Olech et al, 2012) propose the use of large-screen displays to support interaction and information gathering for emergency management. (Rauschert et al, 2002) use a multimodal interface using speech and gesture recognition integrated with GIS functionality. Their project was concerned with aspects of computer vision and speech processing. It assumed the availability of necessary hardware in appropriate places, and was not concerned with possible restrictions due to the emergency or disaster that is being managed. Similarly, (Olech et al, 2012) aims to provide first responders with so-called hotspot locations at which all important information is being displayed. Again, the focus was on software features, based on the assumed available hardware support. Both these approaches presuppose tidy access and clean communication channels. By contrast, our work aims to establish information flow using existing in-situ (interactive) public displays of varying quality and capability, and addresses situations that are potentially considerably less structured and orderly.

5.2 *Semantic modelling for interactive and context-aware systems*

The system and techniques introduced in this chapter are often discussed in relation to context-aware systems.

Context-aware systems measure their context (e.g. location, user, environment etc.) and change their behaviour based on the measured context (Schilit et al, 1994). Context-aware systems are closely related to event-based systems, i.e., systems that react to the detection of events or patterns in their data input stream (Hinze et al, 2009). Examples of event-based systems are those that analyse social media patterns in order to detect events such as earthquakes (Sakaki et al, 2010), or the use of sensor networks in the detection of volcano eruptions (Werner-Allen et al, 2006). The latter system is context-aware as the locations of each of the sensors are taken into account. Other context-aware systems are those that deliver location-based data to mobile users (Cheverst et al, 2000), or support location-based reading of digital books (Hinze and Bainbridge, 2015).

The systems described in this chapter share characteristics with context-aware systems (i.e. measuring of contextual data), but are themselves not context-aware. Instead they communicate to the user the implications about the use of a given interactive system in a given context.

Related work in modelling of, and reasoning for, interactive and context aware systems spans a number of research areas. Traditional knowledge-based systems (KBS) in the field of Artificial Intelligence have the goal of replicating commonsense reasoning ability. They use a *knowledge base* of facts to infer further facts based on rules and conditions, typically encoded in the *inference engine* (Lenat and Guha, 1989). Large ontologies, such as Cyc, contain hierarchies of generic to field-specific knowledge, and rules that give meaning to these facts.

Modelling and reasoning about interactive systems, on the other hand, are a means to ensure the systems' correctness and reliability (Back et al, 1999). The use of ontologies and semantic reasoning is only one way to explore a system's behaviour. Our approach uses the ontology to model different contexts of use.

Our approach is most similar to the ones used in a semantic web context (Berners-Lee et al, 2001). Semantic reasoning in the semantic web is used to infer facts and relationships between concepts (Horrocks et al, 2004b). Our work uses such semantic reasoning as a tool, but does not focus on researching reasoning. Our approach is rather a combination of light-weight reasoning as done in the semantic web context, combined with concepts of event-based and context-ware systems.

6 Conclusions

6.1 Summary

In this chapter we have discussed the use of models to capture both static and dynamic attributes of interactive systems and their environments of use, with the goal of allowing these to be used in non-standard ways to support communications in emergency situations. While there may be many more types of properties and effects than those we have envisaged here, the principles of our approach can be extended to cope with these in the manner described. Similarly, while our initial work relied on ontologies and reasoning using SWRL, there is no reliance on this approach and the models can be used with other tools or methods to the convenience of those adopting them.

So far we have shown two main uses for this type of context/interaction modelling. The first being to support users of systems outside of their typical usage scenario and the second (described in this chapter) to enable a radical approach to emergency communications by providing information about available interactive systems and their remaining behaviours in situations where these are limited by environmental factors. This allows us to answer the sorts of questions posed in Section 2 regarding suitability of devices in given situations at a model/ontology level as well as practically as discussed in Section 4.1.

There are other possible uses of these models, for example to support dynamic configuration of multiple devices by exposing compatible interactive capabilities or for remote management of semi-autonomous systems (like the nuclear power plant from case study one for example) in hazard cases. However, we leave further discussion of these to future work.

6.2 Limitations and Future Work

Although we have presented a method for modelling different types of effects (simple binary effects as well as more fine-grained valued effects such as particular noise levels) there is not guarantee that we can capture and model every possible effect from an unexpected event. This is partly due to the unavailability of all information in an ongoing situation (so there may be things we don't know about which are therefore not included in the model); It may also be due to 'new' effects that have not been experienced before which do not, therefore, fit into the modelling scenario; There are also some effects which may be specialised to an individual (distance of vision or acuity of hearing) or which are composed of multi-layered facets that interact with each other (rubble in front of a display may not only lead to people remaining at a certain distance from the interactive system but may also mean they are at an angle which could also affect vision of anything displayed). Further investigations are required to further understand some of these more complex factors in order to find ways of including them in the modelling approach.

The starting point for the models and subsequent user tools shown here are an ontology. However, building and using ontologies, even with support tools, is both time-consuming and error prone. A thorough understanding of the domains and the reasoning required must be investigated prior to the ontology development. We have experimented with different approaches to the reasoning which do not rely on the ontology. We have also investigated the use of formal modelling (such as formal concept analysis) as a mechanism for supporting the development of the osentology. Both of these strands of research are ongoing.

The proof-of-concept tool suggested here in the prototype shown in Figure 8 is based on a similar tool we have developed for our work in the medical domain. A fuller design project is required to analyse the requirements for this tool with relevant emergency personnel. This should be followed by usability evaluation and testing within the domain, in order to fine-tune the types of information provided and the mechanisms for requesting and updating information.

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