Chapter 2
Understanding and Using Situations

In this chapter we discuss the notion of "situations" as broadly understood across different research fields and then provide an operational definition for it.

2.1 Defining *Situations*

2.1.1 Previous Definitions

Situations have been studied across multiple research areas like ubiquitous/pervasive computing [36, 39], building automation [9], mobile application software [38], aviation/air traffic control [1, 14], robotics [19, 28], industrial control [27], military command and control [35], surveillance [6], linguistics [5], stock market databases [2, 15], and multimodal presentation [25], under the garbs of situation modeling, situation awareness, situation calculus, situation control, and situation semantics. The interpretation of situation however is different across different areas and even across different works within the same area. Here we sample some of the situation definitions employed:

- *Endsley (1988): "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future"*[14]
- *Mooray and Sheridan (2005): "is a shorthand description for keeping track of what is going on around you in a complex, dynamic environment"* [23]
- *Adam (1993): "knowing what is going on so you can figure out what to do"* [1]
- *Jeannot et al. (2003): "what you need to know not to be surprised"* [17]
- *McCarthy et al. (1968): "A situation is a finite sequence of actions "* [21].
- *Yau and Liu (2006): "A situation is a set of contexts in the application over a period of time that affects future system behavior"* [39]

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- *Barwise and Perry (1980): "The world consists not just of objects, or of objects, properties and relations, but of objects having properties and standing in relations to one another. And there are parts of the world, clearly recognized (although not precisely individuated) in common sense and human language. These parts of the world are called situations. Events and episodes are situations in time, scenes are visually perceived situations, changes are sequences of situations, and facts are situations enriched (or polluted) by language "* [4].
- *Dietrich et al. (2004): "...extensive information about the environment to be collected from all sensors independent of their interface technology. Data is transformed into abstract symbols. A combination of symbols leads to representation of current situations ... which can be detected"* [9]
- *Sarter and Woods (1991): "accessibility of a comprehensive and coherent situation representation which is continuously being updated in accordance with the results of recurrent situation assessments"* [30]
- *Dominguez et al. (1994): "the continuous extraction of environmental information along with integration of this information with previous knowledge to form a coherent mental picture, and the end use of that mental picture in directing further perception and anticipating future need"* [10]
- *Smith and Hancock (1995): "adaptive, externally-directed consciousness that has as its products knowledge about a dynamic task environment and directed action within that environment"* [33]
- *Dostal (2007): "the ability to maintain a constant, clear mental picture of relevant information and the tactical situation including friendly and threat situations as well as terrain"* [11]
- *Merriam-Webster dictionary: "relative position or combination of circumstances at a certain moment"* [22]
- *Singh and Jain (2009): "the set of necessary and sufficient world descriptors to decide the control output"* [32]
- *Steinberg et al. (1999): Situation Assessment is "the estimation and prediction of relations among entities, to include force structure and cross force relations, communications and perceptual influences, physical context, etc"* [35]
- *Dousson et al. (1993): "set of event patterns and a set of constraints"* [12]

We clearly see some common traits as well as the dissimilarities among different definitions. Most telling perhaps is the observation by Jakobson et al. that "... *being a relatively new field, there is a clear lack of theoretic well-grounded common definitions, which may be useful across different domains"* [16].

We decided here to focus on the commonalities across definitions and identified the following notions to reverberate across definitions:

1. **Goal based (GB):** situations need to be defined for an application or a purpose.
2. **Space and time (ST):** capture and represent a volume of space and/or time.
3. **Future actions (FA):** support future prediction and/or action taking.
4. **Abstraction (AB):** some form of perception, or symbolic representation for higher cognitive understanding.

Further while some definitions were **computationally grounded (CG)** in data (e.g., Endsley, Dietirch), others were abstract (e.g., Barwise, Merriam-Webster). We summarize the definitions based on these axes in the Table 2.1.

2.1.2 Proposed Definition

Based on observing the common traits as well as a focus on staying computationally grounded, we define a situation as:

"An actionable abstraction of observed spatiotemporal descriptors."

Going right to left, let us consider each of the terms used in this definition:

- **descriptors:** This follows the approach of quantifying an abstract/inexact notion based on sampling its characteristics [13, 26].
- **spatiotemporal:** The most common connotation associated with "situations" (as well as this work's focus) is on spatiotemporal data.
- **observed:** As a computational concept, the focus is only on the "observable" part of the world. Metaphysical as well as physical aspects which cannot be measured by sensors are simply beyond its scope.
- **abstraction:** This signifies the need to represent information at a much higher level than sensor measurements or even their lower-level derivations. Decision-makers typically focus on higher (knowledge) level abstractions while ignoring the lower-level details.
- **actionable:** The top level descriptors and abstractions need to be chosen based on the application domain and the associated output state space. Hence our focus is on creating a representation (e.g., classification) which maps the lower-level details into one concrete output decision descriptor. Hence, we are not interested in *any* higher-level abstraction but rather the *specific* one which supports decision-making in the application considered.

As can be noticed, this definition operationalizes the reverberating threads found across different definitions in literature and computationally grounds them.

2.2 Problem of Situation Recognition

As highlighted by the definition, the essential problem of situation recognition is that of obtaining actionable insights from observed spatiotemporal data. Just like any effort at concept recognition, this problem can be split into three phases, viz., observing data, extracting features, and detecting concepts from the observed features. The unique nature of situation recognition problem is reflected in the spatiotemporal grounding of all data as well as features defined.

Table 2.1 Survey of situation definitions

Work	Goal based	Space time	Future actions	Abstraction	Computationally grounded
Endsley [14]		X	X	X	X
Mooray and Sheridan [23]		o		X	
Adam [1]	X		X		
Jeannot et al. [17]	X				
McCarthy et al. [21]			X		
Yau and Liu [39]	X		X		X
Barwise and Perry [4]		X		X	
Dietrich et al. [9]				X	X
Sarter and Woods [30]		o		X	
Dominguez et al. [10]	X		X	X	X
Smith and Hancock [33]	X	o	X	X	
Dostal [11]		o		X	
Merriam-Webster [22]		o			
Singh and Jain [32]	X		X		X
Steinberg et al. [35]	X		X	X	o
Dousson et al. [12]		o	X	o	X

Note: "o" indicates partial support or coverage. "X" indicates significant support or coverage

2.2.1 Data

Let us represent the observed data at spatiotemporal coordinate st about any particular theme θ as follows:

$$D_{st\theta} = \lambda(\theta, st) \tag{2.1}$$

where

s represents the spatial coordinate of the observation, i.e., $s \in \Re^3$
t represents the temporal coordinate of the observation,
θ represents the application/sensor-specific properties which are observed at the spatiotemporal coordinate
λ is the mapping function from the real-world characteristics to the observation space.

Aggregating over space and time, the data about any particular theme can be referred to as $D_{ST\theta}$, and combining over all observed themes, the data D_{ST} can be represented as:

$$D_{ST} = \{D_{ST\theta_1}, D_{ST\theta_2}, \ldots, D_{ST\theta_k}\} \tag{2.2}$$

2.2.2 Features

A spatiotemporal feature f_{ST} can be obtained via a function Ω applied on the observed data.

$$f_{ST} = \Omega(D_{ST}) \tag{2.3}$$

These features (e.g., growth rates, geographical epicenters, raw values) capture different properties of the observed phenomena and are selected based on their ability to discriminate between the classes of interest.

The combination of features yields a feature set F_{ST} represented as

$$F_{ST} = \{f_{ST1}, f_{ST2}, \ldots, f_{STN}\} \tag{2.4}$$

2.2.3 Situations

Consequently, situations can be derived via a function Ψ applied on the feature set.

$$c_{ST} = \Psi(F_{ST}) \tag{2.5}$$

and $c_{ST} \in C$, where C is the situation universal set. It could be discrete classifications (focus of this work) or values in a certain range. Here

$$C = \{c_1, c_2, \ldots, c_m\} \tag{2.6}$$

where c_1 through c_m are the admissible classes of situation.

To summarize, c_{ST} is the final spatiotemporal situation selected from the range of situations possible, obtained via function Ψ applied on the observed features, which in turn are obtained by applying a function Ω on the observed spatiotemporal data.

Thus the problem of situation recognition is to identify the right situation classification for a given set of observations, i.e.,

$$\Psi \circ \Omega : D_{ST} \rightarrow C \tag{2.7}$$

or alternatively

$$c = \Psi(\Omega(D_{ST})) \tag{2.8}$$

This work aims to define a framework to tackle the situation recognition problem, i.e., extract spatiotemporal features from the observed data, and use them for situation classification.

Note that in this work, we will focus on two dimensions (latitudes and longitudes) for spatial coordinates, i.e., $s \in \Re^2$, and consider the observed values to be real numbers, i.e., $D_{st\theta} \in \Re$.

2.3 Situation-Aware Applications

To define a generic framework for building situation-aware applications, we first survey a variety of situation-aware applications—and identify their commonalities and differences.

Here we discuss 18 of the applications surveyed. These applications correspond to six each from three categories. The first six are applications developed in-house by our team when we started exploring the notion of situation awareness. The next six correspond to academic initiatives to solve situation-related problems. Where needed, we focused on one specific application from large-scale projects. The last six correspond to industrial or governmental efforts at building situation-aware applications.

1. **Flu monitoring and response:** To monitor the number of flu cases and direct at-risk users to vaccination sites [31].
2. **Political event analytics:** To monitor changes in interest in different political figures, parties, and topics.

3. **Business decision-making:** To identify the most suitable location for a new business store.
4. **Allergy/asthma recommendation:** To monitor allergy risk and direct at-risk users to safe locations.
5. **Seasonal pattern analysis:** To monitor when the change in fall colors occurs in New England.
6. **Thailand flood response:** To direct people stuck in unsafe areas to the nearest shelters.
7. **City of Ontario disaster mitigation (RESCUE @ UCI):** To provide information about open shelters, spills, fire, earthquakes, and road closure [3].
8. **Raining cabs (Senseable Cities Lab @ MIT):** Visualize the impact of rain on cab wait times in Singapore [18].
9. **Mapping ideas (Geography Dept. @ SDSU):** To analyze traces of different ideas from cyberspace to the physical geography [34].
10. **Earthquake detection using Twitter (@ Univ. of Tokyo):** Using Twitter feeds to detect earthquakes and send out alerts [29].
11. **Smart classrooms (@ASU):** Student mobile devices react to the situation in the classroom to initiate connections and collaborations [40].
12. **Military situation awareness (@ Bundeswehr University Munich):** Assessment of risk at different locations on the battleground [20].
13. **Plant hardiness zone map (@ US Dept. of Agriculture):** To help gardeners and farmers identify where and when plants grow best by breaking up geographical areas into zones.
14. **Nokia "Situations":** To change the settings (e.g., sounds, alerts) on a mobile phone based on the contextual parameters (e.g., time, location).
15. **Breast cancer application (@VSolveIt):** To identify disease hot spots and suggest clinical trial zones for breast cancer.
16. **US drought impact reporter (@National Drought Mitigation Center):** To provide daily drought risk assessments across the USA.
17. **Situation-based industrial control (@Siemens):** To monitor the state of different processes in an industrial application and take actions based on the situations recognized.
18. **Traffic condition reports (@Google):** To classify freeway traffic conditions based on the speed and the volume.

All the applications follow a general pattern where they import one or more sets of data, do some value addition, and provide the output in different formats. We noticed the following general themes in each of the aspects:

1. **Input Data:** Variety of data being used.

   - **Source:** Sensor based or human report driven (S, H)
     The data used can be either sensor driven or human reports driven. We consider collected data (e.g., census) to be human reports for this discussion.
   - **Timespan:** Real time or archived (R, A)
     The applications either continually evolved with new incoming data or used a snapshot of archived data. It was rare for a single project to consider both these types of data.

- **Diversity:** Homogeneous data or heterogeneous data (H,T)
  The data could be homogeneous or very disparate.

2. **Value addition:** Processing of data streams

- **Integration:** Shallow or deep (S or D)
  Many applications focused on visually placing different data types on a common format (typically map). These can be considered shallow mash-ups. While useful for information consumption, they do not integrate different sources to derive newer information [8]. Deep mash-ups on the other hand allow interoperation between different data types for defining newer variables which affect the situation.
- **Operations used:** Arithmetic logic, value projection, nearest neighbors, spatiotemporal properties (AL, VP, NN, P)
  We noticed four broad categories of operations: those for doing arithmetic, or logical combination, projection of values based on user location, identification of nearest neighbors, and spatiotemporal property extraction (e.g., peak, growth rate, volume).

3. **Output:** Provided to the end users or analysts.

- **Visualization:** Maps, charts, timelines, or text (M, C, T, TX)
  The data could be presented in multiple formats. Maps were by far the most common visualization tool.
- **Actions/Alerts** (AC, AL)
  Potentially such systems could take actions on their own, but we saw most large-scale systems involving humans focus on alerts to them.
- **Querying** (Q)
  Many applications allowed users to query the system to identify values (typically for a particular location).

We summarize these observations in the Table 2.2.

A glance at the table demonstrates the sheer diversity and applicability of situation-aware applications on multiple aspects of human lives. We also notice that while they are disparate, there exist certain commonalities across applications. We revisit the diversity and the commonalities identified (in particular those in data operations) when selecting the generic abstractions for building situation-based applications.

2.4 Design Goals for Framework to Build Situation-Aware Applications

After considering the nature of different situation-aware applications, we proceed to identify the requirements of an effective framework for supporting such applications. We identify three design goals:

Table 2.2 Survey of situation-aware applications and their characteristics

	Inputs			Value addition		Output		
Applications	Source	Time span	Diversity	Integration	Operations	Viz.	Actions	Querying
(1) Flu	H	R	H	D	AL, VP, NN, P	M, T	AL	
(2) Political	H	R	H	D	AL, P	M, T		Q
(3) Business	H	A	H	D	AL, VP, P	M		Q
(4) Allergy	S, H	R	T	D	AL, VP, NN, P	M, T, TX	AL	
(5) Seasonal	H	A	H	D	AL, P	M		Q
(6) Flood	S, H	R	T	D	AL, VP, NN, P	M, T, TX	AL	
(7) Disaster mitigation	S, H	R	T	S	AL, NN, P	M		Q
(8) Cabs	S, H	A	T	S		M		
(9) Mapping ideas	H	A	H	D	AL	M, T		
(10) Earthquake	H	R	H	D	AL, VP, NN, P	M, T	AL	
(11) Smart classrooms	S	R	T	S	AL, NN, P		AC	
(12) Military sit. awareness	S, H	R	T	S	AL, P	M, T		Q
(13) Plant hardiness	S	R	T	D	AL,P	M		Q
(14) Nokia "Situations"	S	R	T	D	AL, P		AC	
(15) Breast cancer	H	A	T	D	AL, VP, P	M		Q
(16) Drought impact	S	R	T	D	AL, P	M		Q
(17) Industrial control	S	R	T	D	AL, P	M	AC	
(18) Traffic condition	S	R	T	D	AL, P	M		Q

Source: sensor based or human report driven (S,H), *Timespan*: real time or archived (R, A), *Diversity*: homogeneous data or heterogeneous data (H,T), *Integration*: shallow or deep (S or D), *Operations*: arithmetic logic, value projection, nearest neighbors, spatiotemporal properties (AL,VP,NN,P), *Visualization*: maps, charts, timelines, or text (M, C, T, TX), *Actions/Alerts*: action taking, alerts (AC, AL), *Querying*: (Q)

1. **Expressive power**
2. **Lower the floor**
   (a) Reduced time to build
   (b) Lower CS expertise required
3. **Raise the ceiling**
   (a) Better designed situation detectors.
   (b) Provide personalization options

The concepts "lower the floor" and "raise the ceiling" are inspired by Myers [24]. Let us discuss what we mean by each of them.

2.4.1 Expressive Power

Given the diversity of applications observed in different applications, a framework designed to recognize situations across them needs to be versatile. This implies that the framework needs to focus on the commonalities and also start with aspects which are common across applications. The last mile specific issues can be left to the individual application designers where required.

2.4.2 Lower the Floor

The framework should resonate with the ideals of [7] in that, "... new breed of applications, often developed by nonprofessional programmers in an iterative and collaborative way, shortens the traditional development process of edit, compile, test, and run. Situational applications are seldom developed from scratch; rather, they are assembled from existing building blocks."

To truly allow web-scale innovation and cater to the "Long tail of (situation) applications" [37], we need to make sure that the situation detectors are easy to build and do not presume computer science expertise. The user input needs to be a declarative specification of *what*. The procedural details of *how* need to be abstracted away wherever possible.

2.4.3 Raise the Ceiling

The framework should not only support situation recognition but also raise the quality of the detectors defined. We consider two different aspects of this raising of the ceiling. First is the design process of the applications. The framework should include design guidelines and wizards to ensure that the designers do not fall into common early mistakes. For example, the designers should not start this process bottom-up, i.e., focus on the data sources available, and think what they can recognize with it; but rather go top-down, i.e., start with the goal and identify the data sources required. Similarly, we want to make addition of different data streams, operators, and features to involve minimal cost. Hence the complexities of operator implementation or writing data wrappers should no longer be a factor in influencing which affordances are provided by an app. Once the design process selects certain modules, they should be available at minimal cost.

Second is the ability to support personalization. Traditional situation recognition and decision-making has focused on single large-scale (e.g., over city, state, country) decision-making. Today, we need tools to individually access each user's inputs and combine this with the surrounding situation for personalized decision-making.

2.5 Components Required for the Framework

In order to support the design goals discussed, we have identified the three important components required for such a framework.

2.5.1 The Building Blocks

To increase the expressive power and to "lower the floor," we need to identify common building blocks which can be used to build a wide variety of applications. The building blocks need to be built upon abstractions which are commonly understood by all application developers and are applicable across different applications (e.g., space and time).

2.5.2 Modeling Approach

To "lower the floor," we need to provide a set of guidelines so that a new application designer is not overwhelmed by the task at hand. Building a system to handle the "flu epidemic in the USA" might appear to be too vague and daunting for a new user. But with some guidance through the design process, the users can break their problem into modular, explicit, and computable chunks. Equally importantly, the resulting guidelines can help "raise the ceiling."

2.5.3 Rapid Prototyping Toolkit

The end goal of the framework is to build working applications for personal and societal good. Hence providing a toolkit (graphical or API based), which allows the users to quickly translate the models into working applications, will tremendously "lower the floor." On the other hand, an ability to rapidly reiterate and redefine the applications will help "raise the ceiling." Further, an ability to personalize the recognized situations and configuring action alerts will help raise the ceiling.

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