Using models to improve display design

When designing human-machine interfaces, like displays, we need to have information about humans. This information can be provided by models. So in this chapter we will first look at how we can model stuff. We then examine how we can use these ideas to design displays. Finally, we examine the principle of workload.

1 Modeling systems

1.1 The abstraction hierarchy

In previous chapters, we have often made models of systems. Models are needed to reduce the complexity of the system. Reducing the complexity can be done in two ways. We can either leave out details of the system, or we can only look at a certain part of the system. For example, we can only look at the purpose of the system.

One way to model a system is by using the **abstraction hierarchy** (AH). The AH splits up the system in levels. Each level then provides the means to realise the next higher level. The AH thus provides a means-ends relationship. Generally, there are five different levels in AH.

- **Functional purpose** – This level describes the goals of the system, which usually is some desired state of the environment.
- **Abstract function** – This contains high level functions, like the physics function which describe the world. (Think of mass and energy conservation laws.)
- **Generalised function** – This level contains functions which describe the processes in the system. (Think of applied aerodynamics/thermodynamics laws.)
- **Physical function** – Here we describe the functions of the actual physical parts of the system. (I.e. what are the functions of all the system parts?)
- **Physical form** – What form do the physical parts of the system have?

To see how this works, we can consider the example of an airplane wing. This wing has a certain physical form/shape. Because it has this shape, it fulfills its physical function, which is providing lift. The lift forces are then transferred to the aircraft fuselage. (This can be seen as the generalised function.) The result is an upward momentum of the aircraft, which is the abstract function. This then achieves the actual functional purpose of the aircraft: staying up in the air. So in this way, each level provides the means for the next level.

Why would we use AH? AH can be useful to discover constraints in the functionality of a system. These constraints can be caused by applying constraints on the function (at functional purpose level), by actual physical laws (at abstract function level), etcetera. Next to this, AH also forms the basis for **ecological interface design** (EID), which will be discussed in the next part.

1.2 Multilevel flow modeling and functional modeling

In **multilevel flow modeling**, we consider every basic unit as a flow structure. Each structure contains a number of flow functions. We can, for example, look at mass flow structures or energy flow structures. Such structures are built up out of several basic elements.

- The places where mass/energy comes from are called **sources**. They are displayed as a circle with a dot.
- The mass/energy disappears again at **sinks**. These are displayed as a circle with a cross.
- Between a source and a sink, we can place a **transport**. This transports mass/energy. It is displayed as a diamond with an arrow.
- Instead of a transport, we can put in a **barrier**. This blocks the flow. It is displayed as a diamond with two diagonal stripes.
- A **storage** is displayed as an empty hexagon. It can contain a (limited) amount of mass/energy.
- A **balance** is displayed as an hexagon with two diagonal stripes. It merges/divides a flow: the sum of inflowing and outflowing mass/energy has to be zero.

Sources, sinks, storages and balances can only be linked to transports and barriers, and vice versa. This linking is done by drawing lines between these elements.

2 Ecological interface design

2.1 Types of machines and instruments

Through evolution, the body and senses of humans are optimized to help us survive in a natural environment. But today, we have a new environment, dominated by technology. We need to make sure that this technology uses our body and senses in an optimal way: in the way which nature used to do.

We can make a distinction between simple machines and complex machines. **Simple machines** (like phones) have a deterministic behavior. Also, if they fail, there is no catastrophy and there are clear instructions on how to deal with this failure. On the other hand, **complex machines** (like airplanes) are not fully deterministic. Using them involves risks, and when a failure occurs, the operators might not be familiar with how to deal with it. To cope with complex systems, a high degree of automation is generally applied.

We can make a distinction between rote instruments and smart instruments. **Rote instruments** consist of a large number of basic type meters. All these meters can be used to derive a large variety of properties. But this can get rather complicated. On the other hand, **smart instruments** specialize on a particular task. Instead of being troubled by constraints, smart instruments use constraints to achieve their goal.

2.2 User-centered design and ecological interface design

Let's try to make an interface as good as possible. A smart approach would be to provide information such that it exploits the human perception. But before we can do that, we have to ask ourselves some important questions.

- **Content** – What are the goal-relevant properties of the environment that need to be measured?
- **Structure** – How are these different properties related?
- **Form** – What visual form should these properties take?

Next to the world, we also need to examine who will use the display. A **user-centered design** (UCD) focuses on the end users, their capabilities, their specific tasks and their preferences. To find out these parameters, we can perform for example a **goal-directed task analysis** or a **competencies analysis**.

In **ecological interface design** (EID), we give priority to the work domain (the **ecology**) of the display. What is the purpose of the system in its environment? What must be done to complete this purpose? How can these (sub)tasks best be accomplished? And how can multiple parts of the system/multiple operators support each other in completing these tasks? EID is useful for complex and safety-critical work environments.

You might be wondering, when should we use UCD and when should we use EID? Basically, we should use EID when we want users to become experts, such that they can handle the unexpected. Do note that EID does not replace UCD. Instead, it complements it.

2.3 The TCAS system

An example where EID can be usefully applied is in the **traffic alert and collision avoidance system** (TCAS). The TCAS estimates the time τ to the **closest point of approach** (CPA) by using

$$\tau = -\frac{R}{\dot{R}}, \tag{2.1}$$

with R the distance towards the other aircraft. There are, however, a couple of issues with the TCAS. The τ parameter is sometimes estimated incorrectly or with a low accuracy. For this reason, pilots are often unsure whether a TCAS warning is correct. This causes the pilot responses to be knowledge-based instead of rule-based, thus increasing the workload.

A possible solution would be to extend TCAS with **automatic dependent surveillance** (ADS). ADS automatically transmits (among others) aircraft position, velocity and heading data. This reduces the inaccuracies of the TCAS system.

Next to this, the TCAS should also be accompanied by a good interface. An example of such an interface is given by the **airborne separation assurance system** (ASAS). This system displays the relative velocity vector of an aircraft with respect to another aircraft. It also displays the vector regions which will cause the aircraft to come into the protected zone of the other aircraft.

3 Workload

3.1 What is workload?

When comparing human-machine systems, there are three important parameters: **operator situation awareness**, **task performance** and **operator workload**. In this part, we'll examine the workload.

There are several definitions of workload. The **task demand load** (TDL) is the mental effort required to accomplish a certain task. The **(task) mental load** ((T)ML) is the amount of mental workload as experienced by the human operator. (While the TDL does not depend on the operator, the ML does.) Finally, there is the **willing-to-spend capacity**. This is the base level of sustainable/acceptable mental load.

There is a relationship between workload and performance. This relationship is characterized by the famous **inverted U graph**. When the workload is too low, there is **underload**: the performance is low. (Think of boredom, dissatisfaction, etcetera.) However, when the workload is too high, the performance is low as well: there is **overload**. (Think of exhaustion, time-shortage, etcetera.) This means that there is an optimal workload somewhere in between, giving the maximum performance.

3.2 Measuring the workload

When designing a system, it would be nice if we can determine the task demand load beforehand. One way in which this can be done is by doing a **task analysis**: how many tasks does the user have at every point in time? And how much effort do these tasks require?

The problem still remains that it is rather subjective to measure the mental load. To reduce these subjective effects as much as possible, workload assessments are subject to several requirements. A few of them are listed now.

- **Selectivity** – The assessment must be immune to other variables, like the emotional load of the test person.
- **Obtrusiveness** – The technique should not interfere with the variable to be measured.
- **Sensitivity** – The assessment should be sensitive to changes in task difficulty.
- **Reliability** – Measuring under identical circumstances should yield identical valus.
- **Consistency among subjects** – There should be little variation between different test persons.

When a user has performed a test, he/she can answer questions about the perceived workload. This kind of measure is called a **subjective measure**. An example of such a subjective measure is the **(modified) Cooper-Harper scale**.

Another subjective measure is the **NASA Task Load IndeX** (NASA TLX). The NASA TLX is a multi-dimensional rating instrument. It has six subscales, being mental demand, physical demand, temporal demand, effort, performance and frustration level. After completion of the task(s), a weight is assigned to each subscale. Subjects then have to rate each task based on the six subscales. Finally, the weights and ratings are combined, resulting in a **weighted rating** for each task. Often, final ratings are normalized, such that the vector of all ratings of a subject has a zero mean and a unity variance. This is called a **Z-score**.

Another way to assess the workload of a task is the **secondary task (dual-task) measure**. Here, human subjects have to do two tasks; one of which is the primary task. When the mental load required for the primary task increases, the performance of the secondary task will decrease. So the performance of the secondary task is a measure of the workload of the primary task.

Workload can also be assessed using **physiological measurements**. We could, for example, look at the pupil diameter of the test person, the heart-rate variability, the evoked brain potentials, the muscle tension or the skin respiration. The downside is that these parameters differ significantly per test person and are also easily influenced by other circumstances.