Building Mental Model Applied to Smartphone Application with ACT-R Cognitive Architecture

Ze Yang, Shota Matsubayashi, Kazuhisa Miwa, Xin Yao

Graduate School of Informatics, Nagoya University
yang@cog.human.nagoya-u.ac.jp

Abstract

This paper proposed two approaches to explain the processes of building and developing mental model applied to smartphone applications. Firstly, we developed two versions of money manager smartphone application. And we did empirical studies to collect user behaviors data and built their mental maps to explain how the users build and change their mental model. Secondly, this research tries to describe the underlying mechanism of the development of mental model based on ACT-R cognitive architecture. The proposed simulation model consists of two sub-functions: *declarative sub-function* and *perceptual sub-function*. Furthermore, it tries to provide a strong proof to describe the mental model mechanisms based on comparing the results between empirical study and ACT-R simulation study.

Keywords — ACT-R, Mental model, Cognitive Architecture, smartphone application, HCI

1. Introduction

In this era of rapid technological advances, the applications play key role in facilitating the development of our daily life and society including communication, education, business and entertainment [1]. In the field of mobile applications, there are special challenges for manufactories to consider how to design a convenient and useful application.

Our study attempts to explain the processes of building and developing mental model applied to smartphone applications in empirical study and simulation study. We did empirical studies to verify how the users build and change their mental model with their mental map. To describe the underlying mechanism of the development of mental model, we designed the cognitive architecture to simulate the processes of building mental model. Finally, we proposed the potential to compare the results between empirical study and simulation study. It can provide the strong proof to describe the mechanisms of mental model.

2. Theory

2.1 Cognitive model

Cognitive architectures offer a computable platform that represents well-established theories about human information processing [2]. With cognitive architectures, it is possible to simulate cognitive mechanisms and structures such as visual perception or memory retrieval. ACT-R (Adaptive Control of Thought-Rational) [3] is the well-developed cognitive architecture used for modeling cognitive mechanisms and human behaviors [4]. In addition, cognitive architecture is both a computational theory of human cognition and a simulation program.

2.2 Mental model

The mental model is defined as an explanation of the human cognitive processing [5]. The cognitive processing of human leading to outcome are a black box, which can be viewed in terms of its inputs and outputs, without any knowledge of its internal workings [6]. It is obviously difficult to explain why such a result is obtained and how mental model is built and developed. However, cognitive models offer explanations about mental processes influencing usability [7]. In general terms, cognitive modeling with ACT-R has the potential to construct mental model and help us to understand the underlying mental mechanisms [8].

3. Empirical Study

3.1 Application design

To compare initial mental model and final one, two types of application are necessary. Thus, we developed two kinds of money manager applications (a fully version and a simplified version). Both applications work equally because they have the same 18 items to implement the main function. But they are some different parts of interface. The differences of their interface design are shown in Table 1.

Table 1 Application interface comparison

		Fully Application	Simplified Application
Main menu		4	3
	Log	Yes	Yes
	Input	Yes	No
	Analysis	Yes	Yes
	Others	Yes	Yes
Max Menu-depth		5 layers	3 layers

3.2 Empirical study

Our goal of empirical study is to demonstrate how users build their mental model while using two different applications sequentially [10]. We measured the states of users' mental model twice; at the time when they used simplified application and fully application. Twenty one participants from Nagoya university took part in the study. At first, they used simplified version application to learn the function of application in advance. Secondly, they used the fully version application to complete task shown as bellow.

- **Task Goal:** *When you travelled abroad in China, you have already stored all your expenses in RMB (Chinese currency). After you came back to Japan, you should calculate how much money your spent in 円.*

3.3 Mental map construction

After participants completed the tasks, we measured the current state of users' mental model by the Mismatching score [9] of each users' mental map. Card sorting method was conducted to measure the users' mental map. In this method, participants were required to sort the 18 cards of application items after completing the task by application. We calculated the Mismatching score between each users' mental map and application structure map. We obtained the data about the process of building and developing the users' mental model.

4. Simulation Study

The empirical study [10] shows that the changes of human mental model after using different versions of applications with same functions. However, the processes of building and developing the human mental model are not clear. Our goal in simulation is to develop an integrated ACT-R cognitive model and simulate the processes of building and developing mental model. By combining application operational information with human perceptual information, integrated model can simulate human thought more closely. Our ACT-R model includes two functions: *Declarative function (DF)* and *Perceptual function (PF)*. Our proposed ACT-R model is developed to illustrate how users build their mental model and change their own mental model while using application to implement tasks.

4.1 ACT-R Model Structure

Our ACT-R model used various modules to implement users' searching, selecting and perceptual behaviors. In the *DF,* information about application structure is processed by the declarative module and its buffers. In the *PF,* visual information and motor movement are controlled by three self-design chunks. Then, the production rules govern the model behavior, which are the core part of ACT-R model. Our proposed ACT-R model is shown in Figure 1.

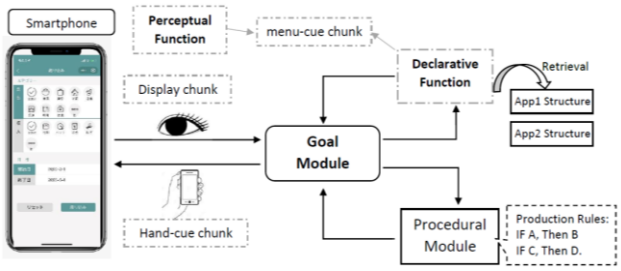

Figure 1 The proposed ACT-R Model Structure

General ACT-R model has five main modules including declarative module, visual module, manual module, procedural module and goal module. On the other hand, our proposed ACT-R model includes two functions and the comparison of them are shown in Table 2.

Table2 Modules of two functions

Module	**DF**	**PF**
Declarative module	Yes	Yes
Visual module	No	Yes
Manual module	No	Yes
Procedural module	Yes	Yes
Goal module	Yes	Yes

Firstly, to simulate the mental map in empirical study, the information of application structure is used to build up representation chunks in declarative module and its buffer. If

the representation chunk is retrieval, it will be used to track the task searching path. The *DF* is used to construct an associated map with the connection nodes between all items in the application. For example, Log-item is a father-node and List-item is a child-node. The relationship between Log- and List-items are connected.

Secondly, to simulate the human behaviors, the *PF* is used to control perceptual information. The *PF* includes three self-design chunks, such as *display chunk, hand-cue chunk and menu-cue chunk,* which are processed by the imaginal module. The imaginal module is used to learn new information and can be checked as working memory. The *display chunk* instead of visual module is consisted of seven slots to define the perceptual information. The perceptual information of items is explained by display chunk, e.g. what size, color, or position the item has. The *hand-cue chunk* instead of manual module is used to detect the hand operations. The *menu-cue chunk* is used to retrieve the structure information of *DF*.

5. Discussion

In the empirical study, we can obtain two mental maps for each participant. Comparing the differences between two mental maps, it can explain the processes of building and developing mental model. Furthermore, in the simulation study, we attempt to explore users' mental processes with ACT-R cognitive model. Comparison between the results of empirical study and computer simulation can provide the strong proof to describe the mechanisms of mental model.

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