CBBC BAMZOOKi™ as a Tool for Engineering Design Research

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Abstract

Organisations across sectors such as aerospace, construction, defence and health care are increasingly being asked not only to provide products in the first instance, but also to support them throughout their service life. Virtually all engineering products are designed using Computer Aided Design (CAD) analysis and simulation systems. Today's CAD systems are excellent tools for recording the end result of a design process, particularly at the detail design stage. However, they are poor at capturing the rationale and underlying intent within the design itself. If CAD systems could automatically capture the reasoning underlying the development of a design then - even years after the original design had been created - engineers could better understand the consequences of potential upgrades and modifications. In order to study this hypothesis, the authors identified the game software CBBC BAMZOOKi as a useful experimental system for the automated capture of design knowledge. This paper explains the reasoning and benefits of using gaming technology for engineering research. An initial analysis of the results of two experiments collecting a total of over 700 design sessions is shown. This data will lead to the automatic generation of design process plans, a first step in understanding the design rational. The paper also discusses if the logging of user actions in other computer games could provide insights in to how people develop problem solving strategies.

Keywords

Engineering Design, User Logging, Knowledge Elicitation

1 Background

Engineering business models are changing - and organisations across sectors such as aerospace, construction, defence and health care are increasingly being asked not only to provide products in the first instance, but also to support them throughout their service life. This requires a new approach to business, operational and information system models which will all need to have sufficient rigour to support product life cycles that could extend to 30 years or more during which the related information and knowledge will be stored, accessed, used and re-created many times over in many different situations and contexts. There are many knowledge management challenges associated with this move towards through-life product support and an essential element of this is the capture of engineering design knowledge.

Virtually all engineering products are designed using computer systems to define component shape and simulate performance. Typically the outcomes of a design activity are recorded as a set of engineering drawings. Indeed today's CAD systems are excellent tools for recording the end result of a design process, particularly at the detail design stage. However, they are poor at capturing the rationale and underlying intent within the design itself. For example if performance tests (either real or virtual) indicate that the stress in a components is too high, its cross-section might be thickened. Likewise if a link in a mechanism collides during movement its shape will be changed. In both these cases the engineering drawings only record the final form of the part and not the underlying reasons for the choice of dimensions. As a consequence of this, when changes are required at a later stage in the product's life cycle, the consequences of these are unclear because the affects of and reasons for previous decisions may not be readily understood since the dependencies within a design are not explicitly represented. Of course an engineer could manually log these dependencies during the design but this would inevitably reduce design productivity, interrupt the engineer's cognitive creative design process and lengthen design lead times. Also there would be no consistency in the quality or structure of the capturing process or the captured information since this would greatly depend on the individual engineers involved in the process. If CAD systems could automatically capture the reasoning underlying the development of a design then - even years after the original design had been created - engineers could understand the consequences of potential upgrades and modifications.

This paper reports research into the potential of automatically recording engineering design activities and developing tools to determine design rational from these records. This paper describes the selection of a game environment, CBBC BAMZOOKi, as an experimental system for the automated capture of design knowledge, and the subsequent experiments and initial results obtained.

2 Capturing Engineering Design Knowledge

The engineering design process has been extensively studied by academic researchers who, based largely on manual observation, have proposed various models in attempts to characterize and structure the activity. Typical of these is the model, similar to that depicted in Figure 1, proposed by Wächtler [Pahl and Beitz 1988] that explicitly models the learning process that develops a design. However many academic models are defined in terms of high-level concepts remote from the details of the design process. Consequently researchers have also reported work that seeks to automatically record the details of what designers actually do, monitoring interactions.

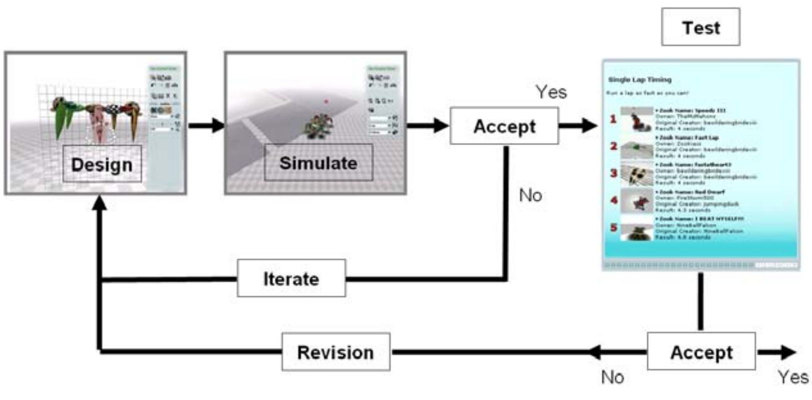


Figure 1: BAMZOOKi Design Cycle

There are studies of engineers' activity interacting with multiple software packages, eg. Campbell et al. [2005] and Stumpf et al. [2005] have studied user behaviour in Microsoft Windows environment, capturing information such as file names, file creation/destruction times, web pages viewed, screen shots, text input, CAD model construction, meta data of files opened etc. Jin and Ishino [2006] use the combination of user activity logging and data mining to automatically generate design activity knowledge. In addition there has been work [Ritchie et al. 1999; Ritchie et al. 2006; Ritchie et al. 2006; Robinson et al. 2006; Robinson et al. 2006; Robinson et al. 2007] demonstrating the use of immersive virtual CAD environments to derive design process knowledge from logs of user activity. This work has provided a vehicle for design task classification and development of an experimental approach which can be extended into the downstream acquisition of knowledge, rationale and design process capture during product design and planning. But there has been little reported on capturing user activity during detailed design activity in conventional PC based CAD systems, and this is the aim of the work reported in this paper.

To allow progress towards the goal of automated design rationale capture in CAD packages, the authors looked for a non-trivial design environment that had the following properties:

- all stages of the design process are supported from conceptualization to functional detailing;
- an intuitive graphical interface allowing non-expert users to participate in the experiment enabling a large number of participants to take part;
- a short design cycle that incorporates integrated in-line testing of mechanical performance;
- a feasible, competitive and engaging design goal;
- measurable design success;
- innate design criteria; and
- accessible data logging.

Initially the proprietary CAD packages such as Pro-Engineer and CATIA were considered. However, they were not able to fulfil all of these requirements, in particular the user interfaces require significant amount of training, and there are only a limited amount of qualified users available to take part in any experiments. The use of current industrial design data is precluded due to commercial sensitivity. The CBBC BAMZOOKi application was identified as providing a self-contained "design-build-test" environment (Figure 1); the structure, operation and interface of which make it an ideal platform for this research. The BAMZOOKi application allows users to construct virtual organic robots (zooks) from building block elements and modify the properties of these elements to change either the form or motion of the zook. The environment also includes a test section where the performance of the zook can be measured against a set of standard tasks.

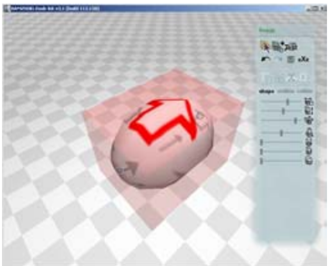
If real-time design and simulation data could be captured while people use the BAMZOOKi application to design, or modify, zooks then it might be possible to post-process the recorded data to extend to automatically extract higher level information about the design itself. For example it might be possible to map the process or provide an accurate description of the problem solving approaches used. The version of the BAMZOOKi software distributed by the BBC does not support any continuous user logging; however, a detailed specification was created and the software's developers, Gameware Development Ltd, modified the package and produced a bespoke version, BAMZOOKi Academic.

3 BAMZOOKi

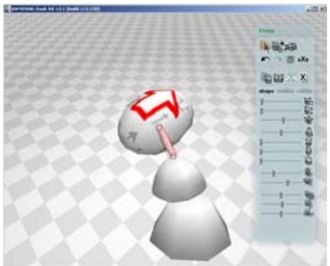
BAMZOOKi was developed for the CBBC, BBC TV's children's channel, and the toolkit is available free for download and standalone use from http://www.bbc.co.uk/cbbc/. Zooks are virtual creatures, or organic robots, that users create to perform with specific mechanical behaviours. Users can then send their zooks into battle with other players' creations, and watch to see who wins. Winning depends on players developing a complex understanding of how to create a zook and what behaviours to design into it to perform. Competitions on the website include sprinting, block push, hurdles and laps.

The BAMZOOKi Zook-kit is an intuitive 3D design environment. The interface allows interaction with 3D models based on "blobs", using simple menus and mouse interaction. In the environment users can either edit/create a zook or test a zook's performance using the simulation animation facility that incorporates a physics engine.

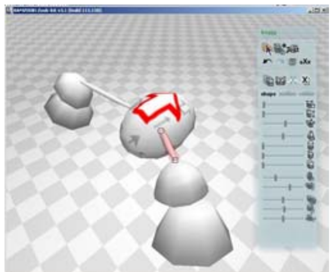
When creating a zook, initially the model is a single blob representing the zook's body as in Figure 2(a). The user can change a number of variables such as: length; width; "squareness"; and "pointiness" to customise the shape of the blobs, either moving the sliders on the menu or dragging key nodes on the model itself. The user can then add blobs, or pre-defined limbs constructed of blobs, to the body as in Figure 2(b). Mirroring tools allow the rapid population of limbs (see Figure 2(c)). In addition to shape variables, blobs have movement variables that can be accessed through the motion tab on the edit menu (Figure 2 (d)) and on screen (Figure 2(e)). At any point during the design cycle, the user can test the Zook by running a simulation animation of the zook using the test tools (Figure 2(f)).



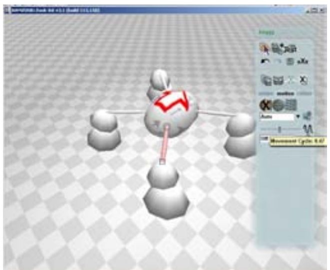
(a) The body



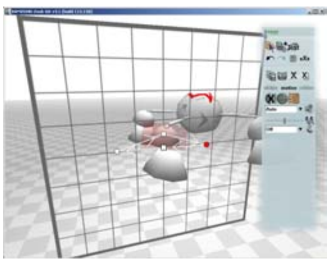
(b) Adding a leg



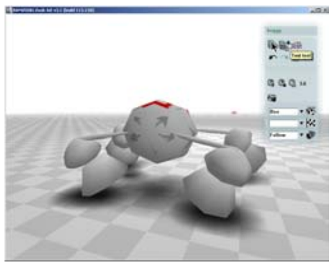
(c) Mirroring a leg



(d) Adjusting the leg phase



(e) Adjusting the leg gait



(f) Testing

Figure 2 - Creating a Zook

Despite its ease of use, BAMZOOKi offers an impressively rich, yet constrained design environment ideal for design task analysis. As one of its developers said:

"*BAMZOOKi's bespoke integrated artificial life technology suite combines physics, artificial intelligence and 3D graphics for anyone who can point and click a mouse. Anyone can play and compete with BAMZOOKi's entertaining and educative system to learn the art of physics, movement, and mechanics with ease through CBBC's engaging online and TV mass media channels. It's simple, fun to use and freely available through CBBC online, yet it's one of the most powerful forms of cyber-plasticine available anywhere."* [Saunter 2005]

4 The Experiment

4.1 Aims

The objective of logging the evaluation sessions is to investigate the processes by which people "discover" what aspects of their design, i.e. the zooks, can best be changed to meet a specific performance goal. There are many options open to the designer to improve the zook's performance: weight reduction; leg lengthening; change of gait etc. Each designer will "discover" which of these parameters has the most effect. The research challenge is to extract this "knowledge" created during the design process from the log files.

4.2 Methodology

Each participant in the experiment was given a default Zook (known as the "Baseline Zook") with a higher performance goal, known as the "Gold" level of performance. The Baseline Zook used in these tests is an eight legged spider and has a "below-average" performance in the three test tasks as defined in Table 1. Its design specifically incorporates "poor" elements that can be identified and modified to improve this performance. Variations of the Baseline Zook can be used to provide different levels, or complexities, of a starting "problem". Example zook problems and possible solutions are detailed in Table 2.

The "Gold" performance is set at a realistic level (average) that can be achieved by a typical user within the timescale of a test session. This is unlikely to be the absolute best performance obtainable and further improvements may possible from a longer session or with more experienced users. Three levels of users were anticipated: beginner, intermediate, and expert users, consequently three sets of goals were developed: apprentice, master and wizard respectively. The performance parameters for these levels are shown in Table 3.

The participants then proceeded to modify the design of the zook to meet this specification by the following procedure.

1. The participant starts the BAMZOOKi session through a "start" dialog box with the Baseline Zook automatically loaded. Each session has a unique log file; this is created and the "header" data completed at the start of the session.

Physical (approx. values):		**Performance:**	
Height:	10 cm	Sprint:	40 cm/s
Width:	30 cm	Block Push:	25 cm
Length:	30 cm	Hurdles:	5 cm/s
Weight:	1 kg		
Components:	22		

Table 1: Baseline Zook Performance Parameters

Problem	**Potential Solution**
Sprint:	
The zook walks rather than runs.	Increase the gate cycle speed.
The zook takes small steps.	Increase the stride length.
Legs are too close to increase stride length.	Increase body length and increase leg spacing.
Legs are too short to have a big stride length.	Increase leg length.
Zook appears to 'limp' or is 'jerky'.	Adjust phase of legs within the gait cycle
Block Push:	
Zook is too small to push the blocks.	Make the zook bigger.
Zook legs contact the blocks rather than the body / head.	Make head larger or change angle of front legs, (etc).
The head makes contact but zook skids on the blocks.	The front of the zook has a point contact, make the jaws larger and wider to produce a more stable contact.
Hurdles:	
Zook gets stuck on the larger hurdles.	Increase the zook's ground clearance.
Zook cannot get onto the larger hurdles.	Change gait cycle to increase step height.
The zook is unstable and sometimes falls over.	Increase width of the zook.

Table 2: Possible Zook Problems and Solutions

Apprentice Level			
Physical (approx. values):		**Performance:**	
Height:	no limit	Sprint:	75 cm/s
Width:	no limit	Block Push:	30 cm
Length:	no limit		
Weight:	2 kg		
Components:	25		
Master Level			
Physical (approx. values):		**Performance:**	
Height:	no limit	Sprint:	75 cm/s
Width:	no limit	Block Push:	30 cm
Length:	no limit	Hurdles:	30 cm/s
Weight:	2 kg		
Components:	25		
Wizard Level			
Physical (approx. values):		**Performance:**	
Height:	15 cm	Sprint:	100 cm/s
Width:	40 cm	Block Push:	50 cm
Length:	35 cm	Hurdles:	75 cm/s
Weight:	2 kg		
Components:	25		

Table 3: Gold Performance Parameters

2. The participant looks at the "My Goal" performance targets for the zook. "My Goal" is a new "pop-up" dialogue box that is activated from the "general zook menu". "My Goal" lists the target "Sprint", "Block Push" and "Hurdle" goals for the session. Then the sequence of actions is typically as follows:
    - The participant tests the baseline zook to see what its current performance is;
    - The participant modifies some aspect of the zook model geometry or motion;
    - The participant tests the zook to see what effect this has had on performance;
    - The participant continues to modify and test the zook until the "Gold" performance target is reached.

All of this activity is recorded in the log file that includes a time stamp to define when events occurred.

3. The participant exits the session. This causes the log file footer data to be added to the log file and the log file to be terminated.

Initial experiments to gather data from novice users took place 10-11 March 2007 during the British Association for the Advancement of Science [http://www.the-ba.net/the-ba.html] "National Science and Engineering Week" (NSEW) exhibition at Satrosphere (Aberdeen's Science Centre) and 2-15 April 2007 at the Edinburgh International Science Festival (EISF) [http://www.sciencefestival.co.uk] at the Wonderama venue. A total of 315 sessions were logged at the NSEW event and a further 475 sessions logged during EISF. The majority of sessions were Apprentice Level at both venues.

5 Data Analysis

The objective of the logging capability is to unobtrusively capture a complete record of each BAMZOOKi design and test session without interrupting the user's cognitive thought process. To be effective during downstream analysis the recorded files must include sufficient detail to enable session activity and evolution of the design to be accurately reconstructed solely from the information contained within the files. It must also be possible to identify all of the files that were created during a single session, e.g. to separate the model geometry file and the corresponding data, say based on time, from the different files used to store this data.

The log data is stored in XML (Extensible Markup Language) [http://en.wikipedia.org/wiki/xml] which is a W3C-recommended general-purpose markup language currently used in the BAMZOOKi application. The primary purpose of XML is to facilitate the sharing of data across different information systems and XML languages are easy to design and to process. Design Activity Categories founded on the work by Robinson et al. [2006] have been built into the structure of the logged XML data, and appear in the log files when the associated events described in Table 4 occur. They define the users activities based on the interaction with the design environment. The aim is to identify events which directly progress the design goal, (eg. creating or changing a body part) as opposed to events which are required by the user interface, such as selecting a body part or menu item.

The hierarchy built into our particular XML schema allows various permutations of the data to be viewed and manipulated. One means of viewing the data is shown in Figure 3 which depicts a simple finite state machine representing typical paths towards achieving a Block Push "Gold" standard. The edges are labelled with the observed percentages that a particular action was performed, depending on the previous action.

In another view shown in Figure 4, the data structure represents the entire log file from beginning to end, displaying the more generic XML Tag definitions rather than specific user interactions. With representations such as these, along with the corresponding data structures, the XML log files automatically generated by BAMZOOKi lend themselves to user behaviour predictions based upon these stochastic observations. That is, the data can be interpreted as a probabilistic model of user behaviour to be developed into a structured design rationale process based upon these observations.

These finite state machine views will allow us observe patterns of user behaviour, in particular once less significant events (such as cosmetic and name changes) are removed we may be able to identify a structured design rationale process. For example if the users goal is to improve the sprint performance, a high level process will be observed which involves changing the leg length (ZookPhysicalEvent), and adjusting the leg gait (ZookDynamicEvent). In these types of observations the key to achieving a representative result is dependant upon procuring a large experimental data set.

XML Tag	Event	Event Possibilities	Category
UI Only	Selection of main panel tab	Select shape, motion and colour tabs	Design Support UI
	Selection of mode	Possible modes: add, edit and test	
	Selection of test buttons	Start timer, stop timer, reset timer, photograph, cool, ramenv, blockpush, sprint, hurdles, high jump	Design Verification
	Achievements from trials		
Zook-Cosmetic	Setting colour	Change rgb colour parameters	Design Goal - Cosmetic
	Setting texture and brightness	Change bitmap and brightness value	
Zook-Dynamic	Setting motion parameters	Movement type, movement control, movement cyle, part targeting	Design Goal - Dynamic
	Moving IK point	Dragging	
	Adding/Deleting IK Point (n/a)	Main panel, keyboard shortcut	
Zook-Physical	Changing body part parameter with panel sliders Changing body part parameter by dragging it around	Change of width, height, length, pointiness, flatten_end_ flatten_side, squareness, base_up-down, base_left-right, twist, tip_up-down,	Design Goal - Physical
	Mirror body part		
	Adding body part (n/a)		
	Deleting/Cutting body part (n/a)	Keyboard shortcut or main panel	
Zook	Selecting body part		Design Support ZOOK
	Selecting IK point		
	Copy body part		
	Undo/Redo	Main panel selection	

Table 4: Design Activity Categories

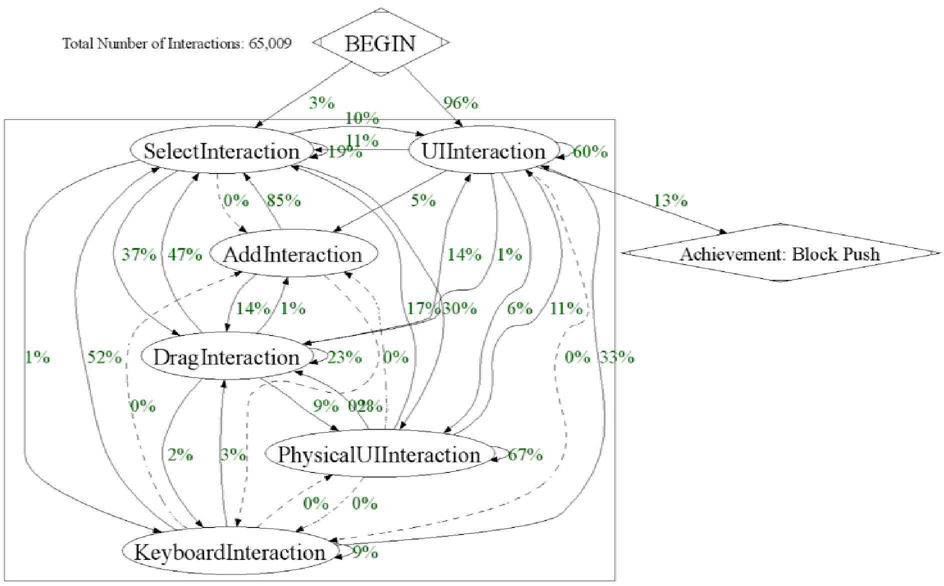


Figure 3: Block Push Finite State Machine

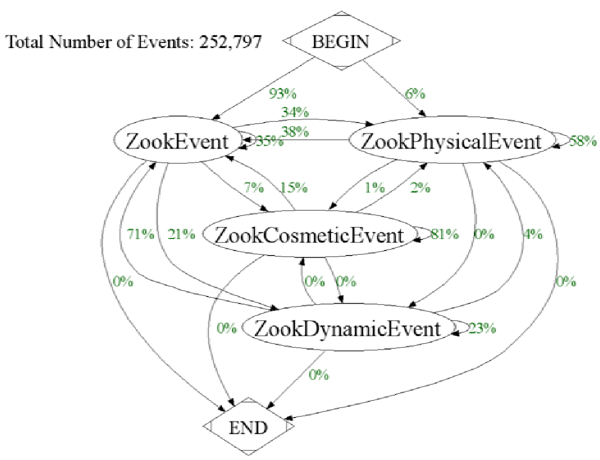


Figure 4: XML Event Finite State Machine

6 Conclusions

This paper has described how a computer game has been used to study the process of engineering design. Although the academic study of engineering design has been researched for over thirty years investigators have always been limited in the tools and data available to them (i.e. interviews and observation). Now, for possibly the first time, computer environments are emerging that are sophisticated enough to allow a component's design to be entirely prototyped and tested with-in one application. Consequently researchers now have the opportunity to study detailed records of the entire process (not simply post-mortem interviews). Using a gaming environment that is appealing and intuitive opens up the potential to generate large amounts of data, and hence the opportunity to use statistical means to analyse the data is viable. Could similar opportunities exist for other academic domains, using other games and environments?

Many other academic disciplines are devoted to the study of human interactions and society (e.g. anthropology, sociology and psychology) and all are constrained by the incomplete information available to researchers. However, the growing sophistication of multi-user, virtual worlds offers many opportunities to study the behaviours of individuals and groups as they engage in problem solving and social interaction. For example in "World of Warcraft©" [http://en.wikipedia.org/wiki/World_of_Warcraft] groups of online players (know as guilds) can form to take on particular challenges. How does the group form? How do leaders emerge? How are decisions made? Potentially researchers could observe and replay these social processes in exhaustive detail.

Likewise in "Second Life©" [http://en.wikipedia.org/wiki/Second_Life] economic business is conducted with goods bought and sold, and again management science is concerned with many aspects of such transactions, for example: "What makes an effective negotiator?", "How are prices determined?" but limited in the physical world by the amount of information available. Some academic work on the economics of virtual worlds has already appeared [The Economist, 2006] but this is studying the life of the virtual world per sea, as distinct from what the authors are advocating: the use of virtual environments to study human processes and interaction through the supply of exhaustive datasets based on the logging of participants' actions.

In all aspects of human endeavour huge variation in an individual's performance are observed. To date the reasons for this have been based on "informed speculation" (e.g. "a leader is successful because he listens to the opinions of his group" or "a leader is successful because he has better ideas than any other member of the group"), however the logging of group interactions, as they pursue quests through virtual worlds, could be used to test such hypothesis through retrospective analysis of conversation; when was an idea, or strategy, first muted and by whom? When did it become the adopted by the group as a whole? Was it successful and if not how did the group deal with failure? Again logs of game play will provide insights and data against which hypotheses can be tested.

The authors believe that the sophisticated Virtual Environments being engineered to support online game play are also creating powerful new experimental tools for the study of problem solving strategies and human interactions.

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Gameware Development is a pioneer of cross media artificial life technology, creating exciting games and interactive communications for TV, PC, console, wireless and hand-held games devices. Based in Cambridge in the United Kingdom, Gameware Development comprises of Creature Labs, the A-Life division fuelling Gameware's development projects, and SceneMachines the mobile technology division evolving and inventing cutting edge intellectual properties to entertain users on the move.

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