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Towards a Theory of Cognitive Mechanisms for Understanding Design

Practices

Ted Tschang

Singapore Management University
Lee Kong Chian School of Business
tedt@smu.edu.sg

Abstract

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Abstract

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1. Introduction

This is an explorative paper that combines findings from a multi year study of “design process” and a partially induced, partially theoretically-derived theory of design mechanisms (which I label ‘cognitive mechanisms’). The area of design thinking and design in general has become a popular area for teaching and proposed practice. In addition, design has also been proposed as a popular lens for conceiving of industry architecture (Jacobides, 2006), organizational structure (Romme, 2003), and business and enterprise design (Osterwalder and Pigneur, 2009).

I am primarily interested in describing a set of cognitive mechanisms observed in the design process – mechanisms which explain “why” and “how” design happens in the fashion it does. To do this, I have relied on evidence from an qualitative field research and other data from the area of game design. Due to the effort to describe the theory here, I do not focus much on the evidence, so this paper should ideally be viewed as a theory development paper.

As I show, what makes the game design process interesting as a general case in point is that not only does it broadly reflect what is going on in design thinking as a set of practices that is infusing other fields, because of its focus on user experience and aesthetics, it also has nuanced differences which do not always come out in other, more traditional forms of design. Game designers craft worlds with a process that involves not only the designer's imagination, but also several other aspects of sense-making, not the least being a conception of aesthetics and player (emotive) involvement/response. Without any of these elements, the description of the process is at best incomplete or even coldly rational, and thus, possibly unsuccessful. My ultimate goal is to show that unless the conception of design science as laid down by Simon (1969) enfolds more generative concepts such as these cognitive mechanisms and sense-making processes, that conception will be an incomplete one.

2. Design and Design Thinking as Means of Innovating

One of the reasons for the recent surge in interest in design thinking is because design is a means of innovation. It may be a straw man to say this, but whereas the preoccupation of innovation studies tends to be on higher level or broader scale theories that have to do less with how innovations come about via specific cognitive or logical mechanisms, and more to do with issues such as its (innovations') management (e.g. team dynamics or product development), character (such as types, "sources", and contingency factors) (Henderson and Clark 1990), processes such as learning or industry dynamics (Utterback and Abernathy 1975). whereas creativity studies tend to focus on highly general

cognitive means behind “idea” formation, true meso-scale approaches that make sense of the innovative mechanisms and interrelationship between those mechanisms and context are fewer in number. The purpose of this paper is not to provide a complete review of such theories. At the same time, a selective review of the literature that explains the character of the innovative process (or the evolution of innovations across industry timescale) in more or less complete mechanisms include theories of modularity founded on logical mechanisms (Baldwin and Clark 2000), and conceptions of how technologies are woven together, and as combinatively and evolved (Arthur 2009; Vincenti 1990).

Phases and Process: A typical view of design involves focus on descriptions of the design process that capture its sources of inspiration (i.e., the research phase into understanding user needs), creativity (focusing on aspects seen in typical brainstorming processes), and finally, the physical manifestation of designs as prototypes for learning and feedback purposes (Osterwalder and Pigneur, 2010). This has been captured in the popular notion of design thinking as a stylized process and set of attendant phases known through Stanford’s “d school” and “the IDEO model”. In truth, this process mimics and incorporates much of what is now conventional in the design field.

This design thinking process is seen to have characteristics that are: (a) highly user-centric, involving detailed observations of individual users, (b) highly iterative and fluid at times (with the central focus on the early stages of the process being more fluid), (c) involves rapid prototyping as a learning process that involves reflection upon user interactions with the prototype (and that is

also fluidly employed), and (d) involves collaboration (usually interdisciplinary). The mechanisms that are popularly depicted and taught in such practices involve solutions being generated through brainstorming and being prototyped for validation with and feedback from users. The process may feed backwards to re-enact earlier stages of the process, even changing the point of view (i.e. problem statement). It is this “lack” of a linear process that causes design thinkers to consider this less processual than a normal process of advancing through stages, or even, that it is not so much about stages as it is about elements of a process in which the stages can be rearranged.

It is my contention that while this has been extremely useful for *design practice* and the *teaching of design practice*, it has not led to any generalizable insights into design as a field.

Combinative and Evolutionary Mechanisms as Synthesis and Generation: A typical means of understanding design thinking has been to conceive of it as an alternating process of expanding the set of ideas or other conceptions, or their reduction by synthesis and other means (Brown 2014; Osterwalder and Pigneur 2010; Owen 1998). While this sort of dichotomy did not directly emanate from any formal cognitive or logical-deductive means of analysis, it has served a useful purpose as a broad categorization capable of capturing the essential tension in design processes.

The question this all begs, however, which is, where do we go with making of a design theory based on more fundamental cognitive mechanisms?

Studies of Design in the Design Studies Tradition

The field of design studies has had more specific and nuanced things to say about what happens during such design processes, including on the cognition end.

Thinking Processes: One of the most commonly understood mechanisms the design process has been seen to involve is that of framing – a concept relatable to Schon (1984). In framing, Schon captured one essential act of the designer as involving adopting a differing perspective. While this perspective taking is more often than not the result of an internal visualization (the creative technique of “taking the opposing view” could be seen as only one manifestation), it actually explains the heart of the design process as being a process of ever changing artifacts and conceptions of artifacts – and provides a logical reason for doing so.

The concept of framing can be related to what is known to occur in design thinking. Design thinking techniques inherently capture the fact that differing world views exist outside of the designer’s own mind, and that some are more akin to what users find to be more amenable. The user’s perspective is thus the most important ‘world view’ representable in the process, but that view is known to be incomplete, given that the data capturing methods employed (e.g. observation and interviews) are at best only able to capture fragments of that view (of user needs, exhibited behaviors, emotions and so forth). Furthermore, this world view can vary widely amongst different users, and may even vary with the user’s emotional state depending on the situation. The servicing of that user’s needs requires a wide exploration of a large solution space through

brainstorming, so again, the incompleteness of whether that “partially captured world view (its needs)” and now “satisfied by a solution that is only believed to meet that need” needs to be tested or validated. In the design view, each of these critical “assumptions” or propositions needs to be tested by prototyping and customer validation.

Another older but more recently promulgated notion of a design mechanism as involving is the type of thinking known as abduction (Martin 2009). Traceable back to Dewey, abduction is actually a third, formal means of logical thinking that is seen in contrast to two other classical forms of logic: deduction and induction. Deduction provides the missing link between incomplete evidence of possible desirable future states (of users’ well being, for instance), and the design itself that could invoke user and other reactions that make those futures plausible ones. It takes the place of the scientific hypothesis, but is in fact the basis for forming a “design hypothesis” based on incomplete knowledge and even possibly circumspect knowledge which may be needed to create more radical visions of the future. Seen this way, it forms an invaluable way of describing the design process, but more critically for my purposes, it could be seen as a link between different cognitively induced “visions” (of the artifact), and a means of selecting amongst or otherwise dealing with the possible states of the world that result from those.

Generativity: Another design mechanism that is often invoked in architecture and relatable to framing (even a generalized form of it) is that of the notion of design as a generative device, that is, that the design process provides for

creative tangents that can emanate from not only a given design perspective adopted, but even constraints (Lawson 2006).

Problem Spaces: Design as a field studying practices (and one with a longer and historical tradition) roughly covers these “steps” or “phases” of the design thinking process, but also construes the designer as developing a problem space that co-evolves with the space of solutions that is explored (Dorst and Cross 2001). In the design thinking process, one problem space is occupied by the “point of view” – a user-centric “problem statement” that designers will also refer to as a “design principle”.

In practice, a designer may partition or break down the problem space, or dimensions, in order to solve it. A true designer may simplify the design, to focus on the most important dimensions, using them to cut across other dimensions. A true designer might move on to another problem space (in effect, the problem space-solution space “co-evolves” (Dorst and Cross 2001)).

While there are other design-specific mechanisms than those, I believe this serves as a useful tour into the “designer’s mind”, or as Cross puts it, the “designerly way” of knowing and acting.

In management, the kind of design thinking approach epitomized by these “mechanisms” is being applied (in parts or wholes) to entities at as high a level as business models (or enterprises, as proposed by the lean start up movement), and as low as product and service designs (i.e. what is termed in the business

model canvas as the “value proposition” or the or product/service bundles that service the customer’s need). To take the “lean startup” view as a case in point: its view of the enterprise is that of one that practices “customer discovery” and “validation”, prototypes by creating a “minimum viable product” (in part to learn from to improve other products), pivoting (i.e. iterating) its value proposition and/or business model as it improves the offering, tests hypotheses, and the means of building a business to implement it (Ries 2011).

The rest of this paper focuses on the description of the cognitive aspects of game design, and how this sheds light on the design thinking process outlined above.

3. The Empirical Context: Game Design

My study primarily consists of qualitative data. Through a study of game design across several studios (concentrating on three) since 2004 through 2014, I have accumulated interviews with 19 designers, other personnel from four design studios, and transcripts of 40 meetings (including about 20 design meetings). In the last visit to one studio which restarted as a small startup, I have also been able to witness first hand and participate in the design changes in a detailed way within a single product.

Game Design as a Design Field

The question arises as to how generalizable the domain of game design is, and what can be learnt from it. While design has been known to be the involve well known fields as “interaction design” (i.e., design of human computer interfaces),

service design, urban planning, and architecture (Buchanan, 1992), notions of what constitutes a design differ wildly across those. In fact, that is because of the particular domains, and means and purposes by which human users interact with those artifacts.

In the same way, game design itself has different purposes and means of interaction than the above mentioned traditional artifacts, and yet, also shares similar aspects with them. Games have user interfaces, present a virtual world of spaces to interact with (as opposed to the physical spaces presented by architecture and planning), and have their own particular notion of entertainment that has to be incorporated into the design (e.g. Salen and Zimmerman 2004, Fullerton 2014).

Game design also shares in common (with some of the other fields) a product nature that is highly interdisciplinary, involving art, animation, interaction and visuals facilitated by technology, and of course, design. The design holds the whole artifact together and presents the user with what is the fundamental experience. What serves as interaction in games involves player entering the designer's "world", and "staying" there for tens of hours per game. The player expects to be challenged, to derive pleasure, and to be "involved" in an experience, often an "epic" one. They do not seek the same pleasures and challenges when operating a mobile phone.

What makes the production of games differing from other design professions is the fact that games rest on a technology bed (involving programming), and are

crafted by teams operating in studios (Tschang, 2007). Game markets can also be highly disrupted due to the influence of technology. A case in point is the recent surge in mobile games. Because the games market are so subject to consumer whims, and platforms, the firms producing games have to in effect “pivot” both their business models and their products to be able to survive (Ries 2012). An illustration of this is the fact that three of the four firms which I had originally studied in the 2004/2005 timeframe had gone out of business, two because of the shifting business environment (and rise of mobile games). One of them had restarted as a mobile games maker, and the CEO continually sought to reposition his business for various investors (in effect, creating options to pivot), including repositioning the product itself, but in the end, failed a second time.

It is because of these commonalities, and yet, differences, that I propose that games are as much a design field requiring of the same kinds of inspiration, creativity and imagination as the other above mentioned design fields. Examples of design cognition are dominated by studies in architecture and product design thus far, but this is starting to change, as is witnessed by the conceptions of organizational design, business model design and industry architecture design.

Thus, to reinforce the earlier point: as similar as the mechanisms and processes may be across design traditions, it is the domains, and what they represent to users, that differ greatly.

4. The Cognitive and Logical Mechanisms Seen in Design

Research Process

To return to the primary contribution of this paper: My primary interest was in understanding how designers think cognitively about their design as they create, or iteratively improve, it. While my study was partly meant to induce mechanisms, relating it to the extant mechanism-driven theories served to be beneficial.

Whereas the notions of thinking inherent in design studies proper consists of mechanisms as abduction, framing, generative thinking and the shifting of problem (and hence, solution) spaces, the explanatory mechanisms I have uncovered in game design trace more directly to the combinative and logical notions behind artifact creation. To arrive at this (and to highlight the origin of my inspiration), I return to the two bodies of work – those of Baldwin and Clark (2000) and Arthur (2007; 2009). Each provides a different perspective (and timescale) on how systems are logically constructed.

Modular Operators: Baldwin and Clark's (2000) study of 'Design Rules' specified a core set of 'modular operators' that were seen to be applied by engineering designers of the IBM 360 (Baldwin and Clark, 2000). While this landmark study is better known as a foundation of modularity theory as well as of the transactions cost approach developed by Baldwin (2008), one of the primary bases for the theory's existence has remained less well known in management. This is the set of "modular operators": augmenting, excluding, inversion, splitting, substitution, and porting. These are in effect not only "logical" but also cognitive (i.e. enacted at some cognitive level) mechanisms that

describe logical operations that designers use to create designs. While the IBM 360 is very much an engineered artifact, some of the same can also be seen in some of the rudimentary acts of game design, albeit construed in somewhat different acts of design for different purposes (i.e., to facilitate user interactivity).

The lower amount of attention paid to such operators may be due to the highly contingent manner by which modular operators operate. For instance, the application of these modular operators to provide a means of determining the contingent nature of product and service evolution within differing business contexts failed to find a generalizable pattern (Woodard et al 2012). It is unlikely however that this represents the end of the applicability of the thinking represented by the modular operators approach, since the former study was mainly involved in the search for a concise yet explanatory mechanism that cleanly resolved the design paths across the four cases. Furthermore, the design process itself is not always traceable to concrete external stimuli or logical resolutions any more than historical studies of engineered artifacts would suggest (Constant 1982; Vincenti 1990). In short, historical studies suggest that many design decisions are incidental, based on the particular circumstances that a technology faces at the given time of its “next evolutionary step” or “leap”.

Combinative Mechanisms: The issue of history raises the second body of work – that of Brian Arthur’s (2007; 2009) - which describes how engineering systems evolve by means of engineers combining components (each founded on some physical scientific principle) into systems – this is what I effectively term “stitching”. Whereas Baldwin and Clark are effectively describing a logical set of

mechanisms in their modular operator concept, in stitching, Arthur is re-introducing the concept of a relatively unknown “future” – one that is “found” through evolution, continual experimental, and in effect, trials at combination. Arthur is rediscovering and promoting the combinative principles of Schumpeter, but at the same time, by operating at the level of the engineering system’s design, is giving form to the actual combinative process.

Since Brian did not attempt to provide a theory with explanatory power, he did not fall afoul of the problems that bedevil the development and application of cognitive and other “design” mechanisms (Woodard et al, 2012). However, amongst the many problems he leaves open is the problem that there is more to the combinative and evolutionary process than just stitching alone. He is also describing this stitching process in a technology’s evolutionary time, but based on my evidence on game design, I see it applying equally well in a given product’s design process, and its evolution during that process.

Mechanisms Witnessed in the Evidence on Game Design

I will turn next to an examination of data to illustrate whether these and other cognitive mechanisms are present in design processes. This is a highly selective exposition of the data, as I am essentially selecting from various sets of data that have been presented more extensively in monograph format.

To synthesize these design and cognitive studies, I will use the evidence I have by classify the data as various “cognitive mechanisms”. I use this both confirm what is seen in the wider design literature - but that also add to it in ways consonant

with the “newer” design literature as represented by the two bodies of work. I illustrate selected of the cognitive mechanisms presented earlier from the literature. This does not pay heed to the iterative process by which theory and evidence was brought together. The mechanisms I have selected to highlight are not game-specific but are more relevant to broader classes of technology and human-created artifacts as well.

In truth, to develop a full set of these for an experience design or industrial design context could be formidable at this stage as the full set of design expressions that convey meaning to users is almost as vast as the set of verbs that can describe user interaction. For instance, just for a single product type’s design as kitchen kettle design, the following design “acts” have been described by one study: Framing; Interlock; Extra Step; Segmentation and Spacing; Self-monitoring; Colour and Contrast; Simulation and Feedforward; Extra step, Prominence and Visibility (Lockton et al 2013). Of course, the complexity goes up with the increasing granularity of detail, and with the introduction of the aspects of the purposes (of design) and forms of user experience (both functional and aesthetical). It is because of this that I will try to stay at the level of what the literature purports to be the most general mechanisms observed in design, and only to open the envelope a bit further to accommodate the two additional bodies of work (Baldwin and Clark’s, and Arthur’s).

For space purposes, I limit the evidence instancing each cognitive mechanism to one illustrative example, usually drawn from secondary data.

Framing: One of the primary cognitive mechanisms well known to design, but that surfaces in my study, is that of framing. Whereas Schon's (1984) idea of framing belies the belief that designers (and similarly, business designers) see the world as constantly changing as new evidence keeps coming in, usually through the designer's reflective process, in game design, framing is as much a part of the continual process known as iterative development – itself a highly rationalized process (Tschang 2007). In game design, framing sometimes seen in the act of insight but more is as often the result of dissatisfaction seen in the design process, or the results of testing processes. A simple act of reframing that “solves” a problem by “using it” was seen in the design of *7th Guest* - Graeme Devine and Rob Landeros adapted to a major obstacle or error in the following way (Demaria and Wilson, 2002):

“(A) problem they encountered turned into a feature in the game. They shot all the actors against blue screens, but apparently, they either used the wrong shade of blue or should have used a green screen. Whatever the problem was, every image had a ghostly aura around it, and it was prohibitively expensive and time consuming to remove all those pixels, so they turned the actors into ghosts, and adapted the game to fit the graphics.”

Modular operators (e.g. substitution - as “adding” or “removing” design elements): In Baldwin and Clark (2000), substitution is a fundamental logical operation, ascribed status as one of only several modular operators. Within the design process, this mechanism is automatically assumed, as designers change designs, and switch solutions in and out. I think it is more fundamental than that,

because, as per Baldwin and Clark, substitution involves selecting out or in elements of a design, and is deeply related to framing (since alternate frames will lead to different elements being emphasized, or left out in the redesign). The other modular operators do also find a place in describing aspects of game design, but the degree is more at a logical level than at a creative level of expression. I have left out the modular operators of splitting (which is more related to engineering), excluding (which is already somewhat related to substitution), or that have not found their equivalent in design (augmenting), and inversion (which has an equivalent expression in creative thinking – which is not a focus of this study). I have also left out some of the more game- and media-specific elements such as narrative design and other forms of (player) progression. In a describing his path-breaking early game in an issue of *Computer Gaming World*, *M.U.L.E.*, Danny Buntin-Berry pointed out how both additions and substitutions occurred:

“With our main design concepts as the skeleton and our scenarios to “flesh out” our ideas, we began to design the way the game would look and work (including the kinds of terrain, commodities, and the rules)...As we went along we developed many of the details that made the game flow better... (for example) We added “ticking timers”...Many things were also taken out as the design was executed...The last pieces written into the game were the best as far as I was concerned”

Porting as Adaptation: The modular operator of porting has an interesting equivalent in that it involves adaptation. In terms of media and world creation,

heavy usage of a mechanism that I label adapting takes place. For instance, the transfer of knowledge from one “world” to another (e.g. from the real to the virtual) was seen with *Silent Service*, one of the first submarine simulations to depict the “real world” of submarine warfare as a simulation. In his designer note on *Silent Service* published in *Computer Gaming World* (a respected but now defunct magazine), Meier discussed the idea of modeling the real world:

“the accelerated-real time (feature)...was designed to overcome the difficulty that has beset most previous computer submarine simulations: the fact that submarine warfare is so episodic,...As a consequence, designs have tended to simplify and distort the situation in order to create a more arcade-like feeling. In contrast, our first design decision was to make the simulation as realistic as possible (the second design decision being to place the player into the captain’s role).”

As can be seen from this fragment, adapting (i.e. the game design equivalent of porting) involves the other mechanisms such as splitting (to modularize) and substitution (to improve the play of the game).

Blending: An important cognitive mechanism that has been left out almost all design discussions so far is blending. Conceptual blending has actually been considered to be a fundamental cognitive act (Fauconnier and Turner 2002), but can be considered to be the cognitive mechanism deeply implicated in any higher level innovation theory relating to combination (see for example, Arthur 2007). Originally, analogical thinking was the default mechanism for describing blends,

and has by now been widely used in explaining work – both scientific and strategic (Lovallo, Clarke, & Camerer, 2012). However, what this does not explain is the design process as a combinative – the contribution of Arthur (Arthur 2007, 2009). This is shown in the following text about the original *Prince of Persia* game (which I also have archival data on whose development):

“The most direct inspiration... (the game The Castles of Doctor Creep) had these ingenious puzzles of the Rube Goldberg sort... So, the one-sentence idea for Prince of Persia was to do a game that combined the ingenuity of The Castles of Doctor Creep with the smooth animation of Karateka...Another inspiration was the first eight minutes of Raiders of the Lost Ark. I wanted to make a game with that kind of action feeling to it. And then there was the Arabian Nights setting. I was looking for a setting that hadn't been done to death in computer games.” (p. 350, Rouse, 2002).

Whereas the first blend may be an act of insight or “instant blend”, to implement this idea may require many other acts of combination and cognitive mechanisms.

Blending is also implied in acts of creativity, though it is harder to study the creative process than “existing acts” as seen in design. It is also worth pointing out that the other design thinking mechanisms of abduction (or prospective thinking) do not explain the processes of design that are invoked by combinative forms of creativity and serendipity, or worse (say in the extreme forms of design science), subsume such generative processes to what seems to be a scientifically-inclined process. Further, an actual design process involves more iterative

processes embodying the set of mechanisms being paid out – to try out ideas, validate them, and reject or embrace them.

Stitching: Another mechanism, following from Arthur (2009), is the idea of stitching. Stitching involves blending, but like adapting, it involves other higher cognitive abilities needed to “make sense” of the design from the user’s perspective. That is, it involves the design equivalent of sense-making. It involves some empathic understanding of what the user experiences. Stitching is often conveyed in game design through the development of a narrative to “stitch” the game together, but could also be employed to combine two or more elements together in a more seamless and elegant (i.e. better experienced) manner, or to reduce complexity by removing elements while “stitching” back the remaining components. In this sense, in my employment of the concept, stitching has more to do with the user experience than it does with the engineered implementation of the game (ensuring it works together at the code level). Game designers have to make sense of the product as they iteratively improve it. Stitching can also be considered to be a higher level mechanism as it allows the designer to emplace the component in a particular logical or creative order, to reconnect them differently (akin to substitution and re-blending), or to remove them (i.e., substitution). *Centipede* creator Ed Logg noted how additions were stitched in once he had the basic concept:

“...Dan Van Elderen asked why the player could not shoot mushrooms. I realized early I would need some means to create new mushrooms. This led to one being left when a centipede segment was shot. I also created the flea which left a trail of them when he

dropped to create more randomness in the pattern..." (Rouse, p. 102).

I have surfaced a few other cognitive mechanisms, and several logical ones (e.g. one on centralization), but most of these are less consequential for capturing the full design processes seen in my data. I submit that I have laid out a set of core mechanisms, including ones not seen in most past design studies.

5. Conclusions

This paper discusses some of the themes emerging from an iterative theoretical development between an empirical design setting and key proposed mechanisms of meso-scale design theory. These are the laying out of a theoretical basis for how various cognitive mechanisms and means of human reflection can portray design processes, and help us explain design outcomes. A side benefit of these is that they are generative, allowing designs to evolve considerably, and hence, avoiding the traps of "computational complexity" that the thinking that Herbert Simon intentionally and unintentionally "placed" design "fields" under. It is worth contrasting the design process as understood in this paper with that earlier view of a design science, because this illustrates the classical design problem of having to explore much wider a space than is possible. In Simon's terms (Simon 1969), bounded rationality would have been employed as the primary instrument and computational means used to solve the "intractable" problem. However, I submit that this does not model the reality of a true design process, or unfold its paradigm.

I would note that inherent within all of these concepts is a knowledge-based view of how process evolves. Aside from the fact that the artifact is continuing to evolve during the design process, new knowledge is at times entering the design process, partly through recollections, but sometimes through new inspirations. This knowledge sometimes enters through the domain itself as (game) domain knowledge, but sometimes originates from other domains, and hence, as “external-to-the-domain” knowledge, can transform the (games) domain.

One implication that is possible is organizational design (or any human-made form’s design) processes might be able to employ some of the “design rules” that these mechanisms embody, allowing the creation of organizational designs from a set of “bottom up rules” (Romme, 2003).

I also believe that these mechanisms help explain what is happening in games as games are essentially a culturally influenced product, and hence, are much more malleable. These mechanisms also reflect what is known in the design literature on cognition. These kinds of cognition can be observed in design thinking processes as practiced in business schools, e.g. in the process of business model innovation.

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