Incorporation of Evolutionary Computation For Implementing The Benefit Of Inconvenience

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Abstract
The present paper discusses the relationship between evolutionary computation (EC) and further benefit of a kind of inconvenience (FUBEN-EKI), which is a research project to explore methods by which to design artifacts while appreciating the benefits of inconvenience. Evolutionary computation contributes to FUBEN-EKI both theoretically and practically. The design theory for implementing the benefits of inconvenience suggests that there are desirable systems between "a stick, a stone, or a handkerchief" and "an optimal system for a certain task." Similarly, exploration vs. exploitation is a key issue in EC, which performs well when the balance between exploration and exploitation is desirable. The present paper also describes how EC contributes, in practice, to the implementation of an explanatory example of a FUBEN-EKI system that uses covariance matrix adaptation evolution strategy (CMA-ES), which is a type of EC, to extract features from multi-dimensional time-series data.

Keywords: Covariance Matrix Adaptation Evolution Strategy, Evolutionary Computation, Further Benefit Of A Kind Of Inconvenience, Multi-Dimensional Time-Series Data

1. Introduction

Convenient systems such as automated systems do not always guarantee high-performance of human-machine systems [1]. In contrast, the auto-adaptation ability of machines may be harmful to human operators [2]. Such abilities spoil the human ability of skill acquisition and of maintaining motivation. The result sometimes causes serious problems for safety engineering. Further Benefit of a Kind of Inconvenience (FUBEN-EKI) [3] is one approach to solving such problems.

Generally, inconvenient tools and methods require labor, skill, and cognitive resources. By focusing on allowance rather than requirement, inconvenience allows users to interact with tools/methods with time/effort and to demonstrate/improve their skills. Such allowance is one of the benefits of inconvenience. Inconvenience allows users to foster their affirmative feelings, instead of sparing them hard work.

Several examples of inconvenient tools and methods are examined in Section 2.1 in order to extract the latent benefits that were overlooked in the process of pursuing only convenience. Generally, the benefits of convenience, i.e., decreasing the amount of time, the labor cost, and the monetary cost, are easy to measure in a quantitative manner. On the other hand, the benefits of inconvenience, i.e., enhancing awareness, allowing exploration, and encouraging creative contribution, are relatively dependent on the individual and are difficult to quantify. For modeling such benefits, Section 2.2 explores qualitative methods, e.g., evolutionary computation.

One way of realizing the benefits of inconvenience, which are obtained from inconvenient tools and methods, is to use physical continuous values that yield fluctuations and user-dependent variations. The explanatory device of FUBEN-EKI reported in Section 3 uses physical variations to compel users to become accustomed to the device, but is beneficial for users in terms of proficiency and personalization.

The point at which designers make an effort is how to handle continuous values that is popular type of data so many analytical techniques have been proposed, e.g., [4]. We use dynamic time warping (DTW) to extract user intentions from time-series data obtained from a 3D acceleration sensor. In this case, finding the correct part of the data can be formalized as a combinatorial optimization problem that can be resolved by naive application of a covariance matrix adaptation evolution strategy (CMA-ES). Evolution strategy (ES) is known as a kind of EC for continuous parameters and has applied to many fields, e.g. [5]. CMA-ES is a stochastic type of ES.
2. Theoretical Relationship between EC and the Benefit of Inconvenience

This section relates EC and the benefit of inconvenience in a theoretical manner. First, we present a brief overview of FUBEN-EKI and discuss relevant research, including research on EC.

2.1. Overview of FUBEN-EKI

Convenience generally implies a reduced labor requirement [6]. Designers develop products that eliminate the need for humans to perform hard work based on the assumption that a more convenient life is a richer life. Although this assumption has yielded technical developments and outcomes that we generally appreciate, technology has also introduced several problems, e.g., the partial-automation problem in the research field of human factors. As another direction of development, we presented FUBEN-EKI and are exploring a method of designing artifacts from the standpoint of appreciating the benefits of inconvenience [3]. Inconvenience enhances awareness, prompts creative contributions, and fosters affirmative feelings.

Have you ever noticed that satisfaction can arise from inconvenience? Consider these examples:

- My bicycle was broken, so I walked to school. It took a long time, but I noticed several things along the way to school. I found a restaurant, which is now one of my favorite places to eat.
- My new car has remote control door locks. It is more convenient than my old car, but the artificial indication devices, i.e., blinking hazard-lamps, do not seem reliable to me. The mechanical noise of the old door locks was comforting.

We refer to such benefits of inconvenience as FUBEN-EKI. Convenient artifacts for daily use exclude the benefits of inconvenience from our lives. Eventually, we take such artifacts for granted, even though we used to live without them, and now we are lost without them. For example, if the power window in my car does not work, I do not know how to close the window without consulting a mechanic. A manually powered window is generally inconvenient but has its own benefits.

2.1.1. Intentional Definition of Convenience

We searched for sentences with the term “convenience” in more than 200 web pages and obtained the following ideas [6]. First, the term “labor saving” is frequently observed and is mainly used in two ways:

- to decrease the amount of labor, and
- to change the character of labor.

Here labor includes not only time-consuming physical tasks but also mental tasks, such as memorization, cerebration, and cognition.

Relativity: Convenience is comparative. One thing is convenient compared to another thing.

Task Dependency: In order to experience convenience, we must be in charge of a certain task, which implies that our feeling of convenience depends on what we want to do.

Protocol Dependency: Convenience varies depending on culture. The diffusion of cellular phones has changed our lives. Most people take the convenience of assured communication channels for granted. In this culture, a person who does not have a cellular phone is considered to be irresponsible.

Following the results of a web search, we naively define the following:

\[
\begin{align*}
\text{convenient} & \equiv \text{saving labor to attain a specific task,} \\
& \text{to decrease the amount of labor,} \\
& \text{to change the character of labor.} \\
\text{time consuming,} \\
\text{special skills \Rightarrow mental load.}
\end{align*}
\]

Based on these definitions, FUBEN-EKI is fairly common in our lives. For example, home-cooked meals, gardening, and sports do not save labor, but we appreciate them.

Although this definition may be insufficient for structuralists, it provides a sufficient understanding of convenience. For example, fatigue consists of the loss of physical energy and mental energy. The former is related to time consumption, and the latter constitutes mental load. The Longman Dictionary explains that “convenience neither spoils your plans nor causes problems.” Avoiding the risk of getting into problems causes a mental load.
2.1.2. Examples of the Benefits of Inconvenience

We examined several examples to determine the benefits of inconvenience based on the assumption that time consuming and requiring special skills imply labor.

**Inconvenient Tools:** The left-hand side of Table 1 shows examples of inconvenient tools and their counterparts. Inconvenient tools are sometimes convenient depending on the context. A few years ago, washboards became very popular in Japan. They save labor when washing special clothes, but they remain in the minority. Table 1 is based on majority preferences and indicates that most people are satisfied with alternatives that are predicted by and prepared by designers, although some people are not satisfied with them and would prefer to perform tasks in other ways.

**Inconvenient Methods:** The right-hand side of Table 1 shows examples of inconvenient methods and their counterparts. Word processors are convenient for creating documents, but handwriting is better for memorizing and remembering what we are thinking about. The benefits of the counterparts of catering, supermarkets, and fast food are the same as for inconvenient tools, e.g., allowing active contributions to tasks. Although assembly conveyor systems in manufacturing save labor on both the overall and individual levels, the Meister system fosters affirmative feelings towards workers, and a worker who can assemble an entire complex product by himself/herself is beneficial for staff assignments. The common benefit of the counterparts of supermarkets, bicycles, TVs in each hotel room, and super express trains, is the chance to experience various events.

<table>
<thead>
<tr>
<th>Tool</th>
<th>Counter example</th>
<th>Method</th>
<th>Counter example</th>
</tr>
</thead>
<tbody>
<tr>
<td>washrub</td>
<td>automatic washing machine</td>
<td>hand writing</td>
<td>word processor</td>
</tr>
<tr>
<td>dial controller</td>
<td>push-button controller</td>
<td>home cooking</td>
<td>catering</td>
</tr>
<tr>
<td>manual transmission</td>
<td>remote lock</td>
<td>kitchen gardening</td>
<td>supermarket shopping</td>
</tr>
<tr>
<td>manual lock</td>
<td>digital camera</td>
<td>slow food</td>
<td>fast food</td>
</tr>
<tr>
<td>non-electronic camera</td>
<td>electric camera</td>
<td>Meister system</td>
<td>conveyor system</td>
</tr>
<tr>
<td>knife</td>
<td>false-color camera</td>
<td>walking</td>
<td>bicycle</td>
</tr>
<tr>
<td>dictionary</td>
<td>electronic dictionary</td>
<td>TV only in lobby</td>
<td>TV in each room of hotel</td>
</tr>
<tr>
<td>public phone</td>
<td>cell phone</td>
<td>local train</td>
<td>super express train</td>
</tr>
</tbody>
</table>

2.1.3. Relations among the Benefits of Inconvenience

Figure 1 shows some of the benefits observed in many inconvenient examples and their contribution relations are denoted by arrowed lines. Bidirectional arrows denote two-way contributions. This section focuses on a number of relevant parts of the figure.

Visibility (allowing systems to be understood through interaction): Tools such as manual transmissions (compared to automatic transmissions) and single-lens reflex cameras (compared to full-auto cameras) are inconvenient when the purpose is to more easily achieve a predefined function. From
these inconvenient tools, we can generally realize the benefit of visibility. Even if their mechanisms are not visible at first, they become clear after we become familiar with the tools.

Some tools have characteristics such that not only their mechanisms but also their usages become visible. Although it is inconvenient if a tool does not afford knowledge of its usage at first glance, such inconvenience often promotes creativity.

Enhancing awareness (allowing exploration): As shown in Section 2.1.2, we can observe the benefits of inconvenience not only from mechanical tools but also from methods. Walking to school instead of using a bicycle provides a chance to find a restaurant. The single TV available at the hotel I was staying at provided the opportunity to make a new friend, who was watching the world cup with me. The convenience of a wide range of goods in supermarkets eliminates the fun of shopping, which is more than simply the labor of accumulating goods.

Based on these examples, we commonly observe the benefit of exploration, which increases the chances of experiencing unexpected events and of innovation. Serendipity is an aspect of innovative thinking. The essence of serendipity is making a discovery by accident and sagacity. Encountering an event by accident and appreciating its value through sagacity can lead to innovation.

Allowing creative contributions to tasks (unsaturated level of proficiency): As shown in the section on visibility, visibility tends to allow users to make creative contributions to tasks and encourage more exploration. Some inconvenient tools/methods do not interfere with our adaptation, and the level of proficiency is not saturated. This benefit fosters affirmative feelings.

2.1.4. Using the benefits of inconvenience

We have determined the benefits of inconvenience from several examples, including those described in the previous section. The following are the benefits that have been determined thus far:

- Fostering affirmative feeling,
- Providing motivation to tasks,
- Personalization [7],
- Putting users at ease.

As shown in Section 2.1.3, there is an abstract guide for realizing these benefits:

- allowing an understanding of systems (visibility),
- allowing exploration (enhance awareness),
- allowing a creative contribution to tasks and unsaturated level of proficiency.

Furthermore, methods for implementing such guidelines have been observed in numerous examples, e.g.,

- use continuity and diversity of physical quantities,
- give a physical presence,
- give a well-worn appeal.

Figure 1 shows some of the relationships among these benefits, guidelines, and implementations. In the figure, rectangular nodes denote normal matters, circular nodes denote inconvenient matters, thick arcs denote implicational relations, dashed arcs denote contribution relations, and ◊ is a modal operator. In the alethic mode, ◊p indicates that the proposition p is possible. In the deontic mode, ◊p indicates that p is permitted. In either mode, even if the value of p varies subjectively depending on the humans attitude, the value of ◊p is objectively determined. For example, for the case in which p denotes “the user becomes skillful at operating the system,” the value of p depends on the user, but the value of ◊p is determined by the system for the case in which ◊p indicates that either “the user can become skillful” or “the system permits users to become skillful.”

Tracing nodes and arcs in Fig. 1 suggests several methods of obtaining the benefits of inconvenience. For example, the hatched area in the figure indicates that there are inconvenient tools or methods that are superficially difficult to operate but that allow users to become skillful at operating by using continuous I/O.
2.2. Relevant Research Fields

2.2.1. Psychological Relevance to Emotional Design

After presenting the psychology of everyday things (POET), D. A. Norman proposed emotional design [7] and claimed that everyday things have to be not only usable but also emotional. One of the main issues of emotional design is personalization. Examples include the placement of furniture, a crack in a glass, and the degradation of tools. These examples imply that personalization should be derived from the usage process, i.e., human-system interaction. Therefore, customization, which allows users to select and adjust the parts and functions prepared by designers beforehand, does not always lead to personalization.

This aspect of emotional design shares many ideas with the benefits of inconvenience, which must allow and encourage contribution to tasks. Although a tool that automatically performs a task only by carrying out an easy operation is convenient, people cannot gain skills with which to accomplish the task or handle the tool as they wish. Similarly, in emotional design, leaving most tasks to tools is not recommended. Making people perform a little more work provides such positive feelings through a sense of accomplishment and pride and connects the users emotionally to the tools.

2.2.2. Candidates of Theoretical Contributors

This section explores candidates for the theoretical basis for characterizing FUBEN-EKI systems. The discussion in Section 2.1 suggests that FUBEN-EKI systems are positioned between “the optimal system for a certain criteria” and “a stick, a stone, or a handkerchief.” The former greatly helps users and is described as convenient, although the usage is tightly regulated. The latter requires skill and is time consuming when carrying out tasks, but the usage is unregulated. The upper part of Table 2 shows these relations. The candidates are required to handle loose constraints. However, the method by which to measure appropriate looseness is unknown. The candidates are also required to process the qualitative characteristics of the systems.

<table>
<thead>
<tr>
<th>Regulated</th>
<th>Loosely constrained</th>
<th>Unregulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>optimal for a task</td>
<td>FUBEN-EKI</td>
<td>stick, stone, etc.</td>
</tr>
<tr>
<td>unique mapping</td>
<td>infomorphism</td>
<td>arbitrary mapping</td>
</tr>
<tr>
<td>regular net</td>
<td>scale-free</td>
<td>random net</td>
</tr>
<tr>
<td>chain, tree</td>
<td>semi-lattice</td>
<td>random graph</td>
</tr>
<tr>
<td>exploitation</td>
<td>EC</td>
<td>exploration</td>
</tr>
</tbody>
</table>

Infomorphism: The first candidate is the infomorphism of channel theory [8], which is a qualitative theory of information that treats the content of information rather than its amount. In this theory, the target problem is divided into local definitions called classifications. Classification \( A \) consists of

- set \( \text{tok}(A) \) of objects to be classified, called the tokens of \( A \),
- set \( \text{typ}(A) \) of objects used to classify the tokens, called the types of \( A \), and
- binary relation \( \models_A \) between \( \text{tok}(A) \) and \( \text{typ}(A) \) indicating the types into which the tokens are classified.

For each \( \alpha \in \text{tok}(A) \) and \( \alpha \in \text{typ}(A) \), \( \alpha \models_A \alpha \) can be interpreted as an assignment of value 1, otherwise 0, to a set \((\alpha, \alpha)\).

Given classifications \( A \) and \( C \), a pair of functions \( (f^\text{typ}: \text{typ}(A) \to \text{typ}(C), f^\text{tok}: \text{tok}(C) \to \text{tok}(A)) \) is called an infomorphism from \( A \) to \( C \), provided that the following holds: \( f^\text{typ}(\epsilon) \models_A \alpha \leftrightarrow \epsilon \models_C f^\text{tok}(\alpha) \) for \( \forall \alpha \in \text{typ}(A) \) and \( \forall \epsilon \in \text{tok}(C) \). An infomorphism is a kind of loose constraint that is not confined to a unique mapping between \( A \) and \( C \) and does not allow fully arbitrary mapping. This characteristic implies the ability of the mathematical formulation of loose constraints.

Network Structure: The second candidate is a network structure. Even if the network scale can be measured by the number of nodes and arcs, its structural complexity has another dimension. The regulation of scale-free [9] is positioned between regular and random. A number of real systems have network structures that are converged into scale-free types.
Another dimension of network structure can be defined. Pattern language [10] was originally a method for designing landscapes, cities, and buildings, but is now used in several research fields, e.g. human-computer interaction [11]. One of its key issues is the semi-lattice network structure. By analyzing a number of landscapes, C. Alexander found that inorganic cities can be modeled as trees of patterns, which are units of objects and events. On the other hand, active cities can be modeled as semi-lattices of patterns. The regulation of being semi-lattice is positioned between being regular (such as chains and trees) and being random graphs.

**Evolutionary Computation (EC):** One promising candidate is EC. From the inconvenient examples shown in Section 2.1, the benefit of exploration is commonly observed. This benefit increases the chance of encountering unexpected events and innovation. Similarly, exploration vs. exploitation is a key issue of EC. Rapid convergence to the optimal solution of a certain criterion eliminates the chance to explore innovative solutions. FUBEN-EKI also warns designers against excessive convergence to a criterion, e.g., labor savings.

A rich diversity of creatures guarantees robustness against environmental fluctuations. Maintaining the diversity of individuals is absolutely critical for EC in dynamic and uncertain environments. In designing systems based on FUBEN-EKI, environmental fluctuation is interpreted as the alteration of perspectives and the usage context. In order to use EC as the basic algorithm for designing such systems, the characteristics of fitness estimations contribute to practical implementations.

### 3. Practical Contributions of CMA-ES to the Benefits of Inconvenience

The previous section discussed the theoretical relations between FUBEN-EKI and related fields of research, e.g., EC. Turning from a theoretical viewpoint to a practical viewpoint, this section demonstrates how EC contributes to the implementation of an explanatory example of FUBEN-EKI.

Among the benefits of inconvenience, we herein focuses on the following:
- chances for exploration,
- physical (not artificial) feedback and physical diversity,
- proficiency.

FUBEN-EKI does not claim that tools or methods should simply be inconvenient. Rather, designers should strive for designs that incorporate the benefits of inconvenience. As an explanatory example of such a device, this section describes an inconvenient input method for mobile devices.

#### 3.1. Inconvenient Input Method

Input methods are evolving toward providing convenient operations. Keyboards, mice, and touchpanels allow discrete and accurate inputs. On the other hand, they ignore the benefit of inconvenience. We are not allowed to explore new usages of keyboards, which convert the diversity of the physical world into binary code through a series of key presses. The result of keyboard operation does not reflect the personal quality of the operator, and input skills are saturated at approximately the same level.

Therefore, we developed a input method for mobile devices that senses user motions using a 3D acceleration sensor. Motion varies by personality and the situation of the operations. In other words, the input method, which is described in this section, takes into account the personality of the user and the fluctuation of user motions.

#### 3.2. Implementing a Learning Process

The proposed input method learns user motions that correspond to commands. For example, the testers of the developed method attempted to make the correspondence relations shown in Table 3.

The upper part of Fig. 2 shows an example of 3D acceleration data that are generated by the command-motion for “I: making a call” by tester 1. Testers are required to repeat the same motion several times at random intervals. The lower part of Fig. 2 shows the degree of similarity when the representative part of the time-series data is set to 241 to 261 on the temporal axis, which is the
horizontal axis in Fig. 2. We use dynamic time warping (DTW) to calculate the similarity. Dynamic time warping is widely used in several pattern matching applications [12].

Table 3. Examples of correspondence between command and motion

<table>
<thead>
<tr>
<th>Command</th>
<th>Tester 1</th>
<th>Tester 2</th>
<th>Tester 3</th>
<th>Tester 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>make a call</td>
<td>put to ear</td>
<td>tilt a few times</td>
<td>form a semicircle</td>
</tr>
<tr>
<td>II</td>
<td>send an email</td>
<td>poke forward</td>
<td>poke forward</td>
<td>poke forward</td>
</tr>
<tr>
<td>III</td>
<td>play music</td>
<td>form a circle</td>
<td>form a circular arc</td>
<td>form a circle</td>
</tr>
</tbody>
</table>

Figure 2. Example of time-series data and result of pattern extraction

Given two time-series of data,

\[ A = a_1, a_2, \ldots, a_M \]
\[ B = b_1, b_2, \ldots, b_N \]

the DTW-distance \( D(A, B) = f(M, N) \) is given as follows:

\[
 f(i, j) = \delta(i, j) + \min \left\{ f(i - 1, j), f(i, j - 1), f(i - 1, j - 1) \right\}
\]

and \( f(0, 0) = 0, f(i, 0) = f(0, j) = \infty \), where \( \delta(i, j) = (a_i - b_j)^2 \). If \( A \) and \( B \) consist of vectors \( a_i \) and \( b_j \), then \( \delta(i, j) = \| a_i - b_j \|^2 \).

For the example shown in Fig. 2, the original data width is \( W = 287 \), \( A \) consists of the data from 241 to 261, and \( M = 20 \). Therefore, the candidates of \( B \) are the data from 0 to 267 (= 287 – \( M \)), and even if we set the bounds 0.5\( M \) \( \leq N \leq 1.5\( M \) (10~30), the number of ways to extract \( B \) from the original data becomes 267 \( \times \) 20.

The problem is extracting the part of the time-series data that represents the intended motion in a self-referential manner. In other words, since \( A \) is not given, all of the DTW-distances among all of the candidates of \( A \) and \( B \) must be enumerated. This problem is configured as follows:

Objectives: The selection of \( A \) from among all of the candidates satisfies the following two objectives:
- \( M \) (length of \( A \)) should be large
- the number of parts that are similar to \( A \) should be large.

Conditions: The conditions of this problem are set as follows:
- For each candidate \( a \) of \( A \), candidate \( b \) of \( B \) is similar if \( (a, b) < m - \sigma / 2 \), where \( m \) and \( \sigma \) are the mean value and variance of \( D(a, b) \).
- \( M/2 \leq N \leq 3M/2 \).
- \( M \leq W/10 \).

Since this problem resembles a combinatorial optimization problem, we focus on EC. As an example of EC, we herein use covariance matrix adaptation-ES (CMA-ES), which is a stochastic optimization method for continuous parameters.
Each individual (x) is represented by a set of two real numbers (x₁, x₂), where 0 ≤ x₁ ≤ 1 and 0 ≤ x₂ ≤ 1. In this case, the dimension of individual is 2, x₁ represents the starting point of part of the time-series data, and sᵣ represents its length. For example, given the data shown in the upper part of Fig. 2, x = (0.8397, 0.6968) represents the part of the original data from 241 (= W × 0.8397) to 261 (= 241 + W/10 × 0.6968). The fitness value of x is set to $S_x^3 \times (L_x - 10)$, where $S_x$ denotes the number of parts that resemble x in the original data and $L_x = W/10 \times x_i$.

We use the recommended empirical values of parameters [13] and a standard CMA-ES algorithm [14]. The generation update is terminated when the generation difference of the fitness values becomes lower than $1.0 \times 10^{-13}$. The best individual of the final generation is selected as the representative part of the data that represent the intended motion of the user.

### 3.3. Matching Process

After learning the command motions of each user, the input method detects these motions within a sequence of user motions. Observing the time-series data of the user motions, the system always calculates the DTW-distances between the input data and the command-motion data, and when one of the distances is dominantly short, the system judges that the corresponding motion has been obtained.

Table 4 shows the results of detecting the command motions of four testers. The error rates are approximately the same among the four persons, but error tendencies depend on the person, e.g., command-motion I of Tester 4 is always detected incorrectly as motion II. The results are satisfactory as the initial states of testers, i.e., the input method is sufficiently inconvenient. The users are required to become accustomed to the input method, which varies depending on the user.

We are currently gathering data to verify that the proposed method allows users to become skillful, as well as the effect of increasing the number of command motions.

### 4. Conclusion

The present paper reports an application of FUBEN-EKI. We stressed that simple applications of evolutionary computations contribute to develop a system that are inconvenient in the FUBEN-EKI sense. Some inconveniences have benefits, as shown in Fig. 1. By employing the diversity and the fluctuation of the physical world, problems that must be addressed by designers can be formulated as combinatorial optimization problems of continuous data.

Regrettably, Section 3 does not catch up with Sections 2. Although EC has more potential for contributing to FUBEN-EKI systems, as discussed in Section 2, the explanatory system described in Section 3 uses EC as a simple tool for solving combinatorial optimization problems.

EC do not necessarily require continuous and differentiable functions for estimating the fitness values of individuals. In designing FUBEN-EKI systems, we must take into account several factors that interact with each other, so that it is quite difficult to configure even quantitative criteria for estimating the values of design candidates.

Ideally, EC will contribute to the conceptual design phase. In this case, each individual in terms of EC represents a design solution candidate, and EC will find a balanced solution that implements the benefits of inconvenience. Excessive exploitation will yield a convenient system for only a certain criterion, and excessive exploration will consume time for evaluating trivial candidates, e.g., a stick, a stone, and a handkerchief.
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