

Estimating Computational Thinking Ability Using Tablets and Electronic Pens

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ABSTRACT

This study proposes a method to estimate a computational thinking ability utilizing handwritten logs. The development of computational thinking skills to build a plan to organize solutions is crucial from an early age. The methods for cultivating these abilities in elementary education are still in the developmental stages. The proposed method analyzes hand-drawing logs obtained through tablets and electronic pens. Participants are assigned illustration tasks utilizing the layer functionality. The transition among layers objectively assesses whether individuals solve tasks in a perspective manner according to a plan. In an experiment involving 24 students and graduate students, an application with seven layers is employed to assign a 20-minute task of replicating a car illustration. From the results, it turns out we can estimate computational thinking abilities from hand-drawing logs. In addition to that, the results reveal the characteristic way of using and holding the pen that occurs when one has a planning perspective unique to computational thinking. This research promotes the ongoing exploration of methodologies for assessing computational thinking skills, particularly in the context of elementary education. It contributes to fostering computational thinking abilities in younger ages.

Keywords: Computational Thinking, Handwritten logs, Machine learning model, Education.

INTRODUCTION

It is crucial to foster computational thinking skills to systematically build a plan toward a solution. Computational thinking refers to the ability to perspectively plan the process of organizing components to solve problems. Research on conceptualizing and evaluating computational thinking skills has progressed [15, 23]. However, the psychological definition and assessment are still in the early stages. The ability of computational thinking is becoming a standard in education in the 21st century [24]. Sue [21] discusses the significance of computational thinking in education. In many countries, computational thinking has been introduced as a mandatory subject in their national curriculums.

Particularly, there have been proposals for educational methods to foster computational thinking using computers. This is because computational thinking skills are derived from a

mindset that originated from programming abilities. Marcos et al [17]. argue that computational thinking is emerging as a set of problem-solving skills that the new generation of students must acquire to fully understand and participate in the computer-based world. Research on computational thinking skills in higher education is advancing [16]. The need for methods is emphasized to identify students with high computational thinking abilities before they learn coding.

In addition to higher education, existing literature supports the inclusion of computational thinking in primary education [17]. However, approaches for children who are not familiar with using computers are still under exploration [5, 10, 11]. Besides, there is a shortage of instructors who can teach programming in primary education, which makes it a challenge to cultivate computational thinking skills in school children. This study proposes a method to examine computational thinking abilities using hand-drawing logs. The method estimates the level of computational thinking ability in individuals based on hand-drawing logs and the transition of layers. Hand-drawing logs are information captured when an electronic pen is in contact with a tablet, including position coordinates, pressure, altitude, and azimuth. Layers refer to stacked films used to draw an illustration gradually.

The method utilizes the upward movement of layers as the illustration is.

To estimate the level of computational thinking ability, the proposed method builds a hidden Markov model to analyze hand-drawing logs. Computational thinking ability can be estimated through illustration creation tasks instead of programming tasks. The method also makes it possible to estimate computational thinking ability in persons who have no experience in making program codes. The proposed method enables us to estimate computational thinking ability even in primary education. Additionally, the development of applications based on the study could allow the estimation of computational thinking ability without persons who have special skills related to programming. It potentially addresses the shortage of instructors who can teach programming in primary education.

This study identifies features in hand-drawing logs of individuals when they exhibit computational thinking abilities. The identification could lead to the development of software that fosters computational thinking abilities through hand drawing in the future. This approach, which uses only commercial devices equipped with facilities for hand drawing, accelerates the implementation of the software.

UTILITY OF HAND-DRAWING LOGS

Computational Thinking Ability

Computational thinking ability, as proposed by Wing [22], is valuable for four reasons:

- 1 identifying and analyzing problems,
- 2 generating ideas for problem-solving,
- 3 developing thinking and expressive skills to realize ideas, and
- 4 persistently collaborating with others to achieve goals.

Computational thinking is categorized into four components: "Decomposition," "Pattern recognition," "Abstraction," and "Algorithms [2]. These components combine to form

computational thinking abilities. Computational thinking is exhibited when designing systems. It involves considering the difficulty of solving a problem, determining the best solution path, and more. Computational thinking, which applies to everyone, can be taught through programming [3]. User Query Intent and Storage of Tags

Education Using Tablets and Electronic Pens

In certain situations, learning with pen-based tablets is as effective as traditional methods using paper and pencil [7, 16, 20]. We can find many active studies on learning methods using pen-based tablets [6, 8, 13, 18, 20]. Tablets are considered less boring devices compared to conventional ones such as paper or PCs [1].

Relationship Between Hand-drawing Logs and Computational Thinking Ability

Christian et al [4]. demonstrate the effectiveness of an unplugged approach for computational thinking ability. Nishigai et al [19]. propose a method to estimate learning behavior based on psychological evaluations using biological information. Asai et al [8]. suggest a method to detect learners' frustration and support request states using online hand-drawing data obtained from devices that support hand-drawing input. They consider frustration a crucial element in determining the presence of a planning perspective in computational thinking.

Maruichi et al [18]. propose a method to estimate learners' confidence using only hand-drawing logs obtained from pen-based tablets. Confidence plays a significant role in learning [12]. Additionally, it is shown that the learning engagement and creativity of learners can be measured using hand-drawing logs obtained with tablets and electronic pens [6, 13].

Computational thinking ability involves a planning perspective through organizing processes toward a goal. Previous studies imply that computational thinking ability can be estimated from hand-drawing logs.

ESTIMATION OF COMPUTATIONAL THINKING ABILITY FROM LAYER TRANSITION

Layer Transition during Computational Thinking

Any person with a plan to solve a problem would assume several stages toward the goal. In hand-drawing, stages correspond to layers. As a constraint to estimate computational thinking ability, the study imposes layers on target persons. The layers are prepared for sketching, line drawing, coloring, and component drawings. Components refer to parts of the drawing content. The proposed method provides target persons with a drawing tool equipped with layer functionality and hand-drawing log measurement capabilities. The overview of the proposed method is shown in Figure 1.

A drawing tool has layer functionality. Using a tablet and an electronic pen, the tool collects hand-drawing logs from a person to whom a drawing task is assigned. The hand-drawing logs are divided into pieces, each manually labeled with states whether the person has a planning perspective.

A machine learning model is trained to estimate computational thinking ability from hand-drawing logs and labels. Relevant features for estimation in the model are extracted to reveal characteristics of individuals exhibiting computational thinking ability.

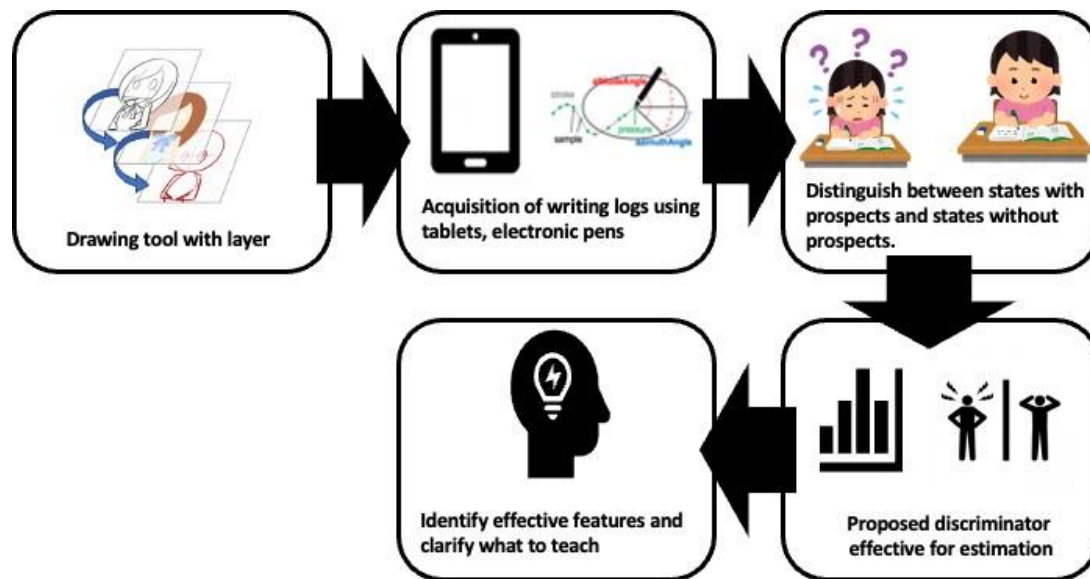


Figure 1: Proposed method.

Role of Layer

In the study, layers play vital roles in estimating computational ability. An overview of the layers is shown in Figure 2. A layer is a transparent virtual sheet used for drawing. Each layer has a specific role. Multiple layers are stacked to create an illustration.

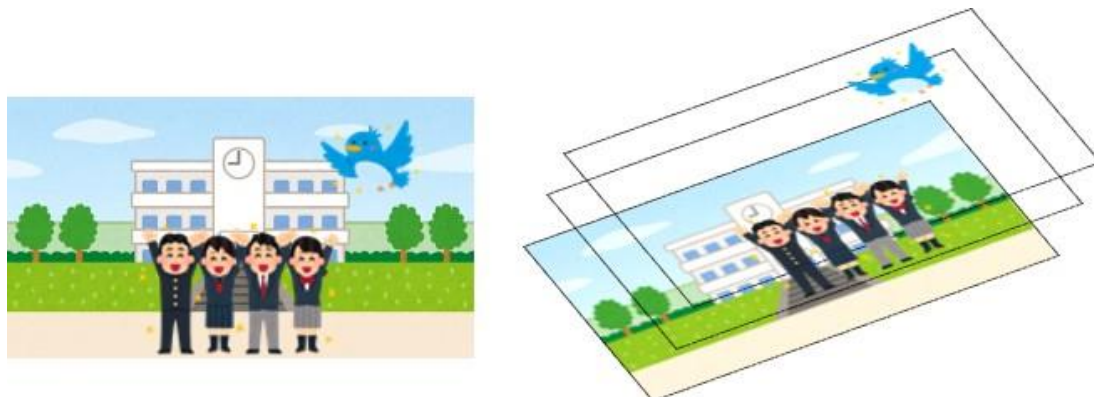


Figure 2: Overview of the Layers

Layers are prepared for sketching, line drawing, coloring, and each component. Users drawing with planning perspectives are considered to plan their sketches during sketching. Persons whose computational thinking ability to be estimated make progress through layers in the order of sketching, line drawing, coloring, and components with minimal backtracking. When they go back to the sketching layer, they give up their planning perspectives. If they repeat going back to the sketching layer, it can be inferred that they are poor at building planning perspectives.

Hand-Drawing Logs

The study measures the position coordinates, pressure, altitude angle, and azimuth obtained from the electronic pen. The obtained data items are shown in Figure 3.

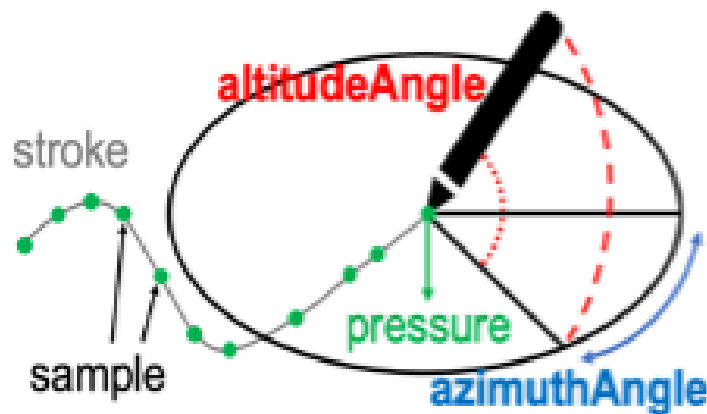


Figure 3: Hand-written logs.

Every 0.1 seconds, data items are captured only when the pen is in contact with the screen of the tablet PC. The position coordinates specify the location where the electronic pen touches the drawing area of the screen, recorded as x and y coordinates up to one decimal place. The location is represented with the left top, the horizontal, and the vertical as the origin, the x-axis, and the y-axis, respectively. The pressure is a numerical representation of the force with which the electronic pen touches the tablet, recorded up to two decimal places, with a maximum value of 4.17. The altitude angle is the angle between the tablet and the pen, expressed in radians, with a maximum value of $\pi/2$. The azimuth is the direction in which the pen is tilted, represented in radians. When the pen is parallel to the x-axis, it is 0, increases clockwise, and decreases counterclockwise. The maximum value is 2π . The pressure, altitude, and azimuth are used as features. The speed at which the electronic pen moves is derived from the difference in position coordinates, also used as a feature. The current selected layer and hand-drawing features are analyzed as explanatory variables.

State Transitions Based on Computational Thinking

For estimating computational thinking ability, examining the frequency of state transitions is effective [6]. When there is a planning perspective, persons are expected to move from the sketching state to the coloring state without returning to sketching. Differences in the frequency of returning to the sketching state are expected to indicate the strength of computational thinking ability.

The layer changes of target persons are visually examined to be labeled. The categories of labels are high and low persons in terms of computational thinking ability. A classifier is trained to distinguish the categories. Features the model uses for classification reveal the characteristics to distinguish the two categories. This analysis helps us identify what should be taught to foster computational thinking ability.

Features from Planning Perspective

When computational thinking ability is exhibited, persons change layers less frequently. Especially, they seldom switch between the drafting and finalizing layers because they have planning perspectives. The method analyzes the differences to reveal distinctions of individuals exhibiting computational thinking ability from others. Focusing on computational thinking ability, it is anticipated that individuals would mainly move among three states during their work:

- state without a planning perspective
- incomplete state
- complete state

A state without a planning perspective corresponds to random sketching. In an incomplete state, a planning perspective is emerging. Persons have their planning perspectives in complete states.

In complete states, it is expected that

- pressure increase because confidence increases, and
- the speed decreases because they tend to draw more carefully.

Persons who do not switch layers from the beginning to the end, maintaining planning perspective throughout, are expected to have fewer transitions between the three states. The features mentioned above would be prominent in hand-drawing logs.

EXPERIMENT AND RESULTS

Environment

To collect hand-drawing logs, this study uses a drawing tool which oblidges layers. Figure 4 shows the environment.

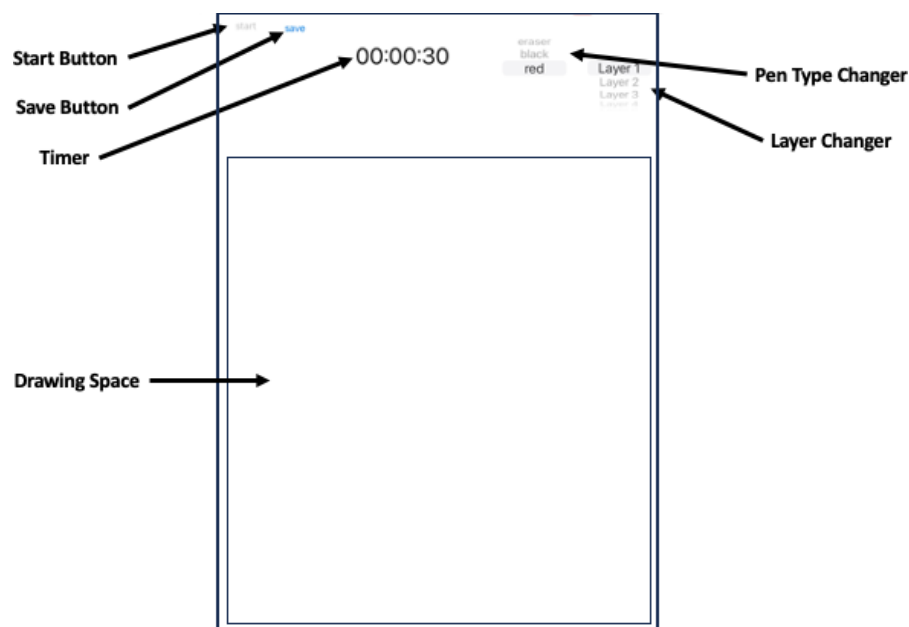


Figure 4: Developed Environment.

iPad and Apple Pencil are used to implement the environment. The tool is implemented using the Swift. It presents the drawing space and functions with a pen and layers using UIView and UIPickerView, respectively. Hand-drawing logs are recorded using an extended UITouch, capturing information from the Apple Pencil. To achieve edit of only drawings in the selected layer, all drawing information in unselected layers are placed in the background. The drawing tool allows users to choose either of the red pen, the black pen, or the eraser. To improve the ease of drawing, the red pen is assigned to sketching, while black one to finalizing. In the

experiment, there are 24 participants in their twenties, consisting of 22 males and 2 females. The participants replicate the image of a car shown in Figure 5.



Figure 5: Image of the Car

Participants divided their drawings into composition, sketching, and finalizing layers. Additionally, specific components to be used on each layer are assigned beforehand. The layers are titled to encourage participants to select them actively. There are seven layers in total, which are shown in Figure 6. One layer is for drawing the overall composition. Three layers are prepared for drawing sketches. Once the sketches are finished, they are copied to another three layers for finalizing. Components are divided into a grille, a body, and tires. Layers are provided for each component, aiming at increasing the frequency of layer transitions.

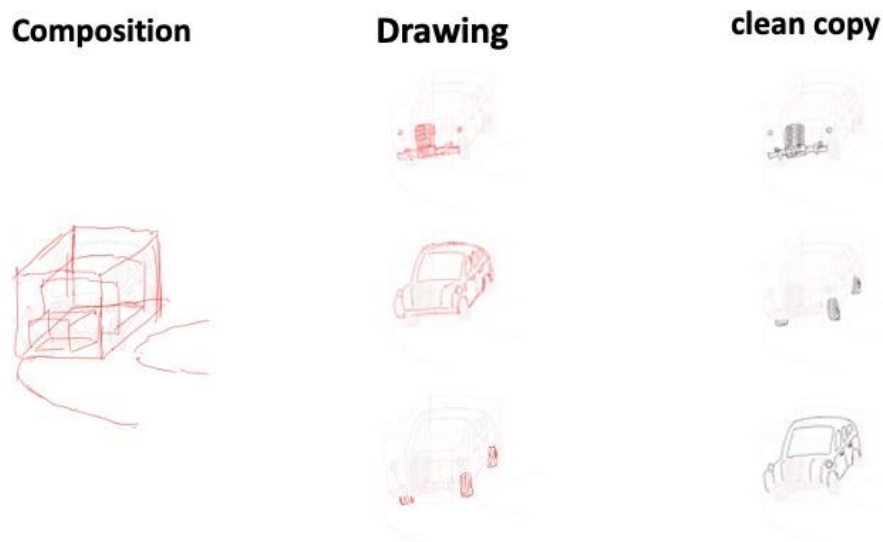


Figure 6: Division of Layers

When the Start button is pressed, the timer starts to measure the drawing time. Pressing the Save button ends the measurement with all the data saved. To align the drawing politeness of all participants, they are asked to finish their illustration approximately 20 minutes before the

experiment. At the same time, to avoid them from rushing, they are permitted to exceed the time limit. Figure 7 is an example of an actual illustration.



Figure 7: Example of an Actual Illustration

Experimental Results

The acquired data need to be preprocessed for the analysis. Due to the nature of hand-drawing characteristics, there is no data when the pen is not in contact with the screen of the tablet PC. Assuming that the participant's state remains unchanged when the pen is not in contact, the data from the previous moment is copied when the pen is lifted. The values indicating the pen type and the selected layer are converted into the One-Hot-Encoding format because they are not categorical. Subsequently, values are standardized for each participant.

A hand-drawing log for each subject is time-series data consisting of multiple data item values. Examining visually the frequency of switching between the drafting and finalizing layers, the time-series data are categorized into 2 groups: data from high and low participants in terms of computational thinking ability. Each type of time-series is used to train a Gaussian Hidden Markov Model for the corresponding group of participants. The model has three hidden states:

- State 0: No planning perspective
- -State 1: Incomplete planning perspective
- State 2: Complete planning perspective

The state of the subjects is believed to change sequentially from 0, 1, to 2.

The transition frequencies of state changes for participants with high and low computational thinking ability are shown in Table 1 and Table 2, respectively. The total numbers and percentages are presented at the bottom.

Table 1: Layer Transition Frequencies for Participants with High Computational Thinking Ability

	From 0 To 1	From 0 To 2	From 1-To0	From 1 to 2	From 2 To 0	From 2 To 1
A	30	39	30	10	38	11
B	35	22	35	0	35	22
C	24	3	25	18	1	19
D	44	9	44	1	9	1
E	9	1	7	2	3	0
F	48	0	48	24	0	24
G	0	17	0	2	17	2
H	73	21	71	2	22	1
I	14	32	13	1	32	0
Total	307	163	205	58	118	80
Percentage	33. 00%	17. 48%	22. 00%	6. 23%	12. 66%	8. 59%

Table 2: Layer Transition Frequencies for Participants with Low Computational Thinking Ability

	From 0 To 1	From 0 To 2	From 1 To 0	From 1 to 2	From 2 To 0	From 2 To 1
J	4	1	4	0	1	0
K	64	18	66	3	16	5
L	17	13	18	1	12	2
M	22	4	22	0	4	0
N	20	8	19	14	9	13
O	5	24	5	0	24	0
P	40	11	40	1	10	1
Q	8	5	7	3	6	2
R	27	12	27	2	11	2
S	5	3	5	12	3	12
T	7	9	7	0	9	0
U	14	15	13	2	15	1
V	30	10	30	0	10	0
W	35	10	33	2	12	0
X	69	4	69	2	3	3
Total	375	132	373	40	107	36
Percentage	35 . 30%	12 . 42%	35 . 10%	3 . 76%	10 . 07%	3 . 39%

The subjects with high computational thinking abilities have tendency to move from state 0 to higher ones. Conversely, transitions from state 1 to state 0 indicate a significantly higher occurrence among subjects with low computational thinking abilities. Tables 3, 4, and 5 present a comparison of drawing features for subjects with high and low computational thinking abilities for each transition state. Table 3, Table 4, and Table 5 correspond to State 0, State 1, and State 2, respectively. As the values are standardized, some may be negative.

Table 3: For State 0.

	Altitude Angle	Azimuth Angle	Force	Speed
Low	-0.1181936	-0.0338291	0.03517578	0.12919678
High	-0.0581577	0.00179947	-0.0082759	0.02356027

Table 4: For State 1.

	Altitude Angle	Azimuth Angle	Force	Speed
Low	0.13070589	0.13707667	-0.0027913	0.09742433
High	0.0602674	-0.1655289	-0.1742155	0.07017613

Table 5: For State 2.

	Altitude Angle	Azimuth Angle	Force	Speed
Low	0.06935467	-0.0521508	-0.018695	-0.1615056
High	0.22586687	0.1777252	0.27185953	-0.0307841

Subjects with high computational thinking abilities exhibit higher azimuth, elevation angle, and pen pressure as the state progresses, with a decrease in speed. When comparing subjects with high and low computational thinking abilities in State 2, those with high abilities have higher values for azimuth, elevation angle, and pen pressure.

DISCUSSION

Characteristics of Transition Frequencies

Subjects with high computational thinking abilities have a higher probability from the state of no planning perspective to the state of complete planning perspectives. It holds for transition from the state of incomplete planning perspective to the state of complete planning perspective. High computational thinking abilities correlate with better transition toward clear plans. High computational thinking facilitates smoother planning and progress.

As for transition from the state of incomplete planning perspective to the state of no planning perspective, subjects with low computational thinking abilities show a higher probability. Low computational thinking abilities result in difficulty in planning, even if they attempt.

Interestingly, subjects with high computational thinking abilities have a higher transition probability toward states of no or incomplete planning perspectives from complete planning perspectives. They tend to lose clarity in planning. However, they easily recover to states of complete planning perspectives as mentioned earlier. Subjects with high computational thinking abilities are likely to get new clear plans even if they change their plans. They might periodically reevaluate their plans for each drawing component.

Differences in Drawing Features

As the state of clarity progresses, the altitude angle increases in both groups. It is observed that when there is clarity and confidence, the pen will stand up. Subjects with higher computational thinking abilities exhibit higher values. The altitude serves as a useful indicator for assessing the manifestation of computational thinking abilities.

Average values of the pen pressure for subjects with high computational thinking abilities increase as the clarity improves. Higher computational thinking abilities correlate with higher pen pressure, reflecting increased concentration. The speed decreases as the state progresses, similar to pen pressure. Concentration leads to slower, more deliberate drawing.

In conclusion, higher computational thinking abilities are associated with higher elevation angle and pen pressure, while lower drawing speed.

CONCLUSION

There is no established method to cultivate computational thinking abilities in students unfamiliar with programming. This study proposes a method using tablets and electronic pens to estimate the abilities without requiring specialized technical knowledge related to programming.

An experiment conducted to validate this methodology identifies drawing features for estimating the presence of computational thinking abilities.

This study classifies the subjects' engagement states into three categories. In the future, focusing on possibilities of the rebuilding plans for each component, it is necessary to divide states further.

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