# Question 1

In engineering design, a function structure is used to represent the core functionality of a technical system in an abstract, implementation-independent way. It describes how material, energy, and information are stored, transmitted, transformed, split, and combined throughout a system. Each function corresponds to a generalized engineering operation and is connected in a directed graph to reflect the system's logical behavior.

The following function structure consists of 50 such functions. Determine what kind of product or technical system this structure is most intended to represent.

Function Structure:

store_material_1 → split_material_with_information_6

store_material_2 → transform_material_9

store_energy_3 → combine_energy_with_material_10

store_information_4 → transform_information_11

store_information_5 → combine_information_with_material_12

split_material_with_information_6 → transmit_material_7

split_material_with_information_6 → transmit_information_8

transmit_material_7 → combine_energy_with_material_10

transmit_information_8 → transmit_information_13

transform_material_9 → combine_information_with_material_12

combine_energy_with_material_10 → split_energy_with_material_14

transform_information_11 → transmit_information_17

combine_information_with_material_12 → combine_information_with_information_18

transmit_information_13 → combine_information_with_information_18

split_energy_with_material_14 → transmit_energy_15

split_energy_with_material_14 → shape_material_16

transmit_energy_15 → combine_energy_with_energy_20

shape_material_16 → transmit_material_21

transmit_information_17 → combine_information_with_energy_22

combine_information_with_information_18 → combine_information_with_energy_24

store_energy_19 → combine_energy_with_energy_20

combine_energy_with_energy_20 → combine_information_with_energy_22

transmit_material_21 → shape_material_25

combine_information_with_energy_22 → combine_information_with_information_26

store_energy_23 → combine_information_with_energy_24

combine_information_with_energy_24 → combine_information_with_information_26

shape_material_25 → transmit_material_27

combine_information_with_information_26 → transmit_information_28

transmit_material_27 → split_material_with_information_29

transmit_information_28 → split_information_with_information_32

split_material_with_information_29 → shape_material_30

split_material_with_information_29 → transmit_information_31

shape_material_30 → transmit_material_35

transmit_information_31 → combine_information_with_energy_37

split_information_with_information_32 → shape_information_33

split_information_with_information_32 → shape_information_34

shape_information_33 → split_information_with_information_38

shape_information_34 → transform_information_41

transmit_material_35 → transform_material_42

store_energy_36 → combine_information_with_energy_37

combine_information_with_energy_37 → transform_information_43

split_information_with_information_38 → transmit_information_39

split_information_with_information_38 → transmit_information_40

transmit_information_39 → store_information_44

transmit_information_40 → shape_information_45

transform_information_41 → shape_information_46

transform_material_42 → store_material_47

transform_information_43 → combine_information_with_energy_49

store_information_44 → combine_information_with_material_50

store_material_47 → combine_information_with_material_50

store_energy_48 → combine_information_with_energy_49

combine_information_with_energy_49 → combine_information_with_material_50

## expected answer:

Manufacturing plant with information feedback loop

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## Question 2 (GPT4o)

In engineering design, a function structure is used to represent the core functionality of a technical system in an abstract, implementation-independent way. It describes how material, energy, and information are stored, transmitted, transformed, split, and combined throughout a system. Each function corresponds to a generalized engineering operation and is connected in a directed graph to reflect the system's logical behavior.

The following function structure consists of 27 such functions. Determine what kind of product or technical system this structure is most intended to represent.

store_energy_1 → transmit_energy_2

transmit_energy_2 → transform_energy_3

transform_energy_3 → transmit_energy_4

transmit_energy_4 → transform_energy_5

store_material_6 → transform_material_7

transform_material_7 → transmit_material_8

store_information_9 → transmit_information_10

store_energy_10a → combine_energy_with_information_11

transmit_information_10 → combine_energy_with_information_11

combine_energy_with_information_11 → transform_energy_12

transform_energy_12 → store_energy_13

store_information_14 → transmit_information_15

store_material_15a → combine_material_with_information_16

transmit_information_15 → combine_material_with_information_16

combine_material_with_information_16 → transform_material_17

store_energy_18 → transform_energy_19

transform_energy_19 → transmit_energy_20

transmit_energy_20 → transform_energy_21

transform_energy_21 → split_energy_with_information_22

split_energy_with_information_22 → transmit_information_23

split_energy_with_information_22 → transmit_energy_24

store_information_25 → transmit_information_26

transmit_information_26 → transform_information_27

### expected answer:

A Bicycle

## Question 3

You are given the following 30 Roth functions, categorized by entity (material, energy, information):

Material:

store_material

transmit_material

shape_material

transform_material

split_material_with_material

split_material_with_energy

split_material_with_information

combine_material_with_material

combine_material_with_energy

combine_material_with_information

Energy:

store_energy

transmit_energy

shape_energy

transform_energy

split_energy_with_energy

split_energy_with_material

split_energy_with_information

combine_energy_with_energy

combine_energy_with_material

combine_energy_with_information

Information:

store_information

transmit_information

shape_information

transform_information

split_information_with_information

split_information_with_material

split_information_with_energy

combine_information_with_information

combine_information_with_material

combine_information_with_energy

Now consider the following technical system:

A system includes a wound spring that stores energy. The energy is transmitted through a gear train. The train drives multiple output shafts, each rotating at a different rate. These outputs are connected to rotating indicators. A manually operated control element allows the user to modify the state of the gear train.

Using the Roth functions listed above, infer a function structure that represents this system. The structure should identify the functions involved, their associated entities, and how they are connected, such that it reflects the internal functional decomposition of the described product.

### expected answer:

A working function structure

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## Question 4 (GPT4o)

A system includes a wound spring that stores energy. The energy is transmitted through a gear train. The train drives multiple output shafts, each rotating at a different rate. These outputs are connected to rotating indicators. A manually operated control element allows the user to modify the state of the gear train. What type of product or technical system is most likely being described?

### expected answer:

A mechanical watch or clock.

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## Question 5

A product is composed of the following functions.

store_energy_1 → transmit_energy_2

transmit_energy_2 → transform_energy_3

transform_energy_3 → transmit_energy_4

transmit_energy_4 → transform_energy_5

store_material_6 → transform_material_7

transform_material_7 → transmit_material_8

store_information_9 → transmit_information_10

store_energy_10a → combine_energy_with_information_11

transmit_information_10 → combine_energy_with_information_11

combine_energy_with_information_11 → transform_energy_12

transform_energy_12 → store_energy_13

store_information_14 → transmit_information_15

store_material_15a → combine_material_with_information_16

transmit_information_15 → combine_material_with_information_16

combine_material_with_information_16 → transform_material_17

store_energy_18 → transform_energy_19

transform_energy_19 → transmit_energy_20

transmit_energy_20 → transform_energy_21

transform_energy_21 → split_energy_with_information_22

split_energy_with_information_22 → transmit_information_23

split_energy_with_information_22 → transmit_energy_24

store_information_25 → transmit_information_26

transmit_information_26 → transform_information_27

Would this product be suitable for outdoor fitness activities?

### expected answer:

Yes, since it is the function structure of a bicycle.

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## Question 6 (GPT4o)

A system is composed of the following 5 functions.

store_information_0 → combine_information_with_information_1

store_information_2 → transmit_information_3

transmit_information_3 → combine_information_with_information_1

combine_information_with_information_1 → transmit_information_4

transmit_information_4 → store_information_5

Would this system be suitable for live video conferencing?

### expected answer:

No, there are functions missing.

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## Question 7

A system performs the following functions:

store_energy_1 → transmit_energy_2

transmit_energy_2 → transform_energy_3

transform_energy_3 → transmit_energy_4

store_material_5 → transmit_material_6

transmit_material_6 → transform_material_7

store_information_8 → transmit_information_9

A product development team wants to use this system as the core of an automated metal 3D printer. Based on the function structure, is this a reasonable application?

### expected answer:

Yes, it is suitable.

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## Question 8 (GPT4o)

The following functions define a system:

store_material_1 → split_material_with_information_2

split_material_with_information_2 → transmit_material_3

transmit_material_3 → shape_material_4

shape_material_4 → transmit_material_5

transmit_material_5 → transform_material_6

Would this system be suitable for analyzing brain activity in real time?

### expected answer:

No, energy functions are missing.

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## Question 9

You are given a function structure consisting of several connected general functions (see below), and a catalog of Solution Principles. Each Solution Principle covers exactly one function and may include an input constraint - a function that must precede it in the structure, or an output constraint - a function that may replace or prune successors if it is already present.

Your task is to select a minimal set of Solution Principles that fully covers the entire function structure. Also ensure that all constraints are respected. If a constraint matches an existing function in the structure, you may reuse it. If a constraint is not present, you may add new functions to fulfill it, but only when necessary.

Function Structure:

store_material_1 → store_material_5

store_energy_2 → combine_energy_with_material_6

store_energy_3 → split_energy_with_information_7

store_information_4 → combine_information_with_information_10

store_material_5 → combine_energy_with_material_6

split_energy_with_information_7 → transmit_energy_8

split_energy_with_information_7 → transmit_information_9

transmit_information_9 → combine_information_with_information_10

Catalog:

Name: store_material1

Function: store_material

Input constraint: store_energy

Output constraint: transmit_energy

Name: store_material2

Function: store_material

Input constraint: store_information

Output constraint: split_material_with_material

Name: store_material3

Function: store_material

Input constraint: combine_material_with_information

Output constraint: transmit_information

Name: store_material4

Function: store_material

Input constraint: transform_energy

Output constraint: store_energy

Name: store_material5

Function: store_material

Input constraint: shape_information

Output constraint: shape_energy

Name: store_material6

Function: store_material

Input constraint: combine_material_with_energy

Output constraint: transform_energy

Name: store_material7

Function: store_material

Input constraint: combine_material_with_material

Output constraint: split_material_with_information

Name: store_material8

Function: store_material

Input constraint: transmit_energy

Output constraint: transmit_energy

Name: store_material9

Function: store_material

Input constraint: None

Output constraint: shape_information

Name: store_material10

Function: store_material

Input constraint: None

Output constraint: None

Name: transmit_material1

Function: transmit_material

Input constraint: None

Output constraint: store_energy

Name: transmit_material2

Function: transmit_material

Input constraint: store_information

Output constraint: None

Name: transmit_material3

Function: transmit_material

Input constraint: None

Output constraint: transmit_information

Name: transmit_material4

Function: transmit_material

Input constraint: transmit_energy

Output constraint: shape_information

Name: transmit_material5

Function: transmit_material

Input constraint: None

Output constraint: split_material_with_material

Name: transmit_material6

Function: transmit_material

Input constraint: store_information

Output constraint: transmit_information

Name: transmit_material7

Function: transmit_material

Input constraint: shape_energy

Output constraint: transmit_energy

Name: transmit_material8

Function: transmit_material

Input constraint: None

Output constraint: transform_information

Name: transmit_material9

Function: transmit_material

Input constraint: None

Output constraint: split_material_with_material

Name: transmit_material10

Function: transmit_material

Input constraint: transform_energy

Output constraint: transform_information

Name: shape_material1

Function: shape_material

Input constraint: transmit_information

Output constraint: store_information

Name: shape_material2

Function: shape_material

Input constraint: shape_energy

Output constraint: None

Name: shape_material3

Function: shape_material

Input constraint: transform_information

Output constraint: split_material_with_information

Name: shape_material4

Function: shape_material

Input constraint: transform_information

Output constraint: None

Name: shape_material5

Function: shape_material

Input constraint: None

Output constraint: shape_energy

Name: shape_material6

Function: shape_material

Input constraint: store_information

Output constraint: transform_energy

Name: shape_material7

Function: shape_material

Input constraint: store_energy

Output constraint: split_material_with_material

Name: shape_material8

Function: shape_material

Input constraint: shape_information

Output constraint: store_information

Name: shape_material9

Function: shape_material

Input constraint: combine_material_with_material

Output constraint: split_material_with_energy

Name: shape_material10

Function: shape_material

Input constraint: combine_material_with_information

Output constraint: None

Name: transform_material1

Function: transform_material

Input constraint: None

Output constraint: None

Name: transform_material2

Function: transform_material

Input constraint: None

Output constraint: split_material_with_energy

Name: transform_material3

Function: transform_material

Input constraint: combine_material_with_energy

Output constraint: store_energy

Name: transform_material4

Function: transform_material

Input constraint: transform_energy

Output constraint: split_material_with_material

Name: transform_material5

Function: transform_material

Input constraint: None

Output constraint: None

Name: transform_material6

Function: transform_material

Input constraint: transmit_energy

Output constraint: shape_energy

Name: transform_material7

Function: transform_material

Input constraint: None

Output constraint: split_material_with_energy

Name: transform_material8

Function: transform_material

Input constraint: store_information

Output constraint: store_information

Name: transform_material9

Function: transform_material

Input constraint: None

Output constraint: split_material_with_information

Name: transform_material10

Function: transform_material

Input constraint: combine_material_with_information

Output constraint: None

Name: split_material_with_material1

Function: split_material_with_material

Input constraint: combine_material_with_material

Output constraint: transform_energy

Name: split_material_with_material2

Function: split_material_with_material

Input constraint: combine_material_with_energy

Output constraint: shape_information

Name: split_material_with_material3

Function: split_material_with_material

Input constraint: transform_information

Output constraint: transmit_energy

Name: split_material_with_material4

Function: split_material_with_material

Input constraint: combine_material_with_material

Output constraint: store_energy

Name: split_material_with_material5

Function: split_material_with_material

Input constraint: combine_material_with_information

Output constraint: store_information

Name: split_material_with_material6

Function: split_material_with_material

Input constraint: transmit_energy

Output constraint: transmit_information

Name: split_material_with_material7

Function: split_material_with_material

Input constraint: combine_material_with_material

Output constraint: transmit_information

Name: split_material_with_material8

Function: split_material_with_material

Input constraint: None

Output constraint: split_material_with_information

Name: split_material_with_material9

Function: split_material_with_material

Input constraint: None

Output constraint: split_material_with_energy

Name: split_material_with_material10

Function: split_material_with_material

Input constraint: transform_information

Output constraint: shape_information

Name: split_material_with_energy1

Function: split_material_with_energy

Input constraint: combine_material_with_energy

Output constraint: store_information

Name: split_material_with_energy2

Function: split_material_with_energy

Input constraint: store_information

Output constraint: store_energy

Name: split_material_with_energy3

Function: split_material_with_energy

Input constraint: store_energy

Output constraint: transform_energy

Name: split_material_with_energy4

Function: split_material_with_energy

Input constraint: None

Output constraint: split_material_with_information

Name: split_material_with_energy5

Function: split_material_with_energy

Input constraint: None

Output constraint: None

Name: split_material_with_energy6

Function: split_material_with_energy

Input constraint: combine_material_with_material

Output constraint: transmit_energy

Name: split_material_with_energy7

Function: split_material_with_energy

Input constraint: None

Output constraint: transform_information

Name: split_material_with_energy8

Function: split_material_with_energy

Input constraint: None

Output constraint: None

Name: split_material_with_energy9

Function: split_material_with_energy

Input constraint: None

Output constraint: transmit_information

Name: split_material_with_energy10

Function: split_material_with_energy

Input constraint: transform_energy

Output constraint: store_information

Name: split_material_with_information1

Function: split_material_with_information

Input constraint: None

Output constraint: shape_energy

Name: split_material_with_information2

Function: split_material_with_information

Input constraint: store_information

Output constraint: store_energy

Name: split_material_with_information3

Function: split_material_with_information

Input constraint: combine_material_with_information

Output constraint: split_material_with_energy

Name: split_material_with_information4

Function: split_material_with_information

Input constraint: combine_material_with_material

Output constraint: None

Name: split_material_with_information5

Function: split_material_with_information

Input constraint: combine_material_with_material

Output constraint: store_information

Name: split_material_with_information6

Function: split_material_with_information

Input constraint: store_energy

Output constraint: transmit_energy

Name: split_material_with_information7

Function: split_material_with_information

Input constraint: transform_energy

Output constraint: None

Name: split_material_with_information8

Function: split_material_with_information

Input constraint: None

Output constraint: transmit_information

Name: split_material_with_information9

Function: split_material_with_information

Input constraint: transform_information

Output constraint: split_material_with_energy

Name: split_material_with_information10

Function: split_material_with_information

Input constraint: shape_information

Output constraint: transmit_energy

Name: combine_material_with_material1

Function: combine_material_with_material

Input constraint: transform_information

Output constraint: split_material_with_information

Name: combine_material_with_material2

Function: combine_material_with_material

Input constraint: None

Output constraint: split_material_with_material

Name: combine_material_with_material3

Function: combine_material_with_material

Input constraint: transform_information

Output constraint: None

Name: combine_material_with_material4

Function: combine_material_with_material

Input constraint: store_energy

Output constraint: None

Name: combine_material_with_material5

Function: combine_material_with_material

Input constraint: store_energy

Output constraint: shape_information

Name: combine_material_with_material6

Function: combine_material_with_material

Input constraint: combine_material_with_energy

Output constraint: transmit_energy

Name: combine_material_with_material7

Function: combine_material_with_material

Input constraint: None

Output constraint: None

Name: combine_material_with_material8

Function: combine_material_with_material

Input constraint: transform_energy

Output constraint: shape_information

Name: combine_material_with_material9

Function: combine_material_with_material

Input constraint: shape_energy

Output constraint: None

Name: combine_material_with_material10

Function: combine_material_with_material

Input constraint: shape_information

Output constraint: None

Name: combine_material_with_energy1

Function: combine_material_with_energy

Input constraint: transform_information

Output constraint: transmit_energy

Name: combine_material_with_energy2

Function: combine_material_with_energy

Input constraint: transmit_information

Output constraint: None

Name: combine_material_with_energy3

Function: combine_material_with_energy

Input constraint: store_information

Output constraint: split_material_with_material

Name: combine_material_with_energy4

Function: combine_material_with_energy

Input constraint: shape_energy

Output constraint: split_material_with_information

Name: combine_material_with_energy5

Function: combine_material_with_energy

Input constraint: None

Output constraint: shape_information

Name: combine_material_with_energy6

Function: combine_material_with_energy

Input constraint: store_energy

Output constraint: None

Name: combine_material_with_energy7

Function: combine_material_with_energy

Input constraint: combine_material_with_material

Output constraint: None

Name: combine_material_with_energy8

Function: combine_material_with_energy

Input constraint: combine_material_with_information

Output constraint: transform_information

Name: combine_material_with_energy9

Function: combine_material_with_energy

Input constraint: transform_information

Output constraint: None

Name: combine_material_with_energy10

Function: combine_material_with_energy

Input constraint: None

Output constraint: shape_energy

Name: combine_material_with_information1

Function: combine_material_with_information

Input constraint: combine_material_with_energy

Output constraint: transform_energy

Name: combine_material_with_information2

Function: combine_material_with_information

Input constraint: store_information

Output constraint: transform_energy

Name: combine_material_with_information3

Function: combine_material_with_information

Input constraint: None

Output constraint: None

Name: combine_material_with_information4

Function: combine_material_with_information

Input constraint: transmit_energy

Output constraint: None

Name: combine_material_with_information5

Function: combine_material_with_information

Input constraint: shape_information

Output constraint: split_material_with_energy

Name: combine_material_with_information6

Function: combine_material_with_information

Input constraint: combine_material_with_energy

Output constraint: transmit_energy

Name: combine_material_with_information7

Function: combine_material_with_information

Input constraint: combine_material_with_material

Output constraint: shape_energy

Name: combine_material_with_information8

Function: combine_material_with_information

Input constraint: shape_energy

Output constraint: split_material_with_material

Name: combine_material_with_information9

Function: combine_material_with_information

Input constraint: transform_energy

Output constraint: split_material_with_energy

Name: combine_material_with_information10

Function: combine_material_with_information

Input constraint: None

Output constraint: transform_information

Name: store_energy1

Function: store_energy

Input constraint: None

Output constraint: transmit_information

Name: store_energy2

Function: store_energy

Input constraint: combine_energy_with_energy

Output constraint: None

Name: store_energy3

Function: store_energy

Input constraint: None

Output constraint: split_energy_with_information

Name: store_energy4

Function: store_energy

Input constraint: combine_energy_with_energy

Output constraint: split_energy_with_material

Name: store_energy5

Function: store_energy

Input constraint: shape_material

Output constraint: transform_information

Name: store_energy6

Function: store_energy

Input constraint: combine_energy_with_information

Output constraint: transmit_material

Name: store_energy7

Function: store_energy

Input constraint: store_information

Output constraint: split_energy_with_energy

Name: store_energy8

Function: store_energy

Input constraint: transform_information

Output constraint: shape_material

Name: store_energy9

Function: store_energy

Input constraint: combine_energy_with_material

Output constraint: store_information

Name: store_energy10

Function: store_energy

Input constraint: None

Output constraint: shape_information

Name: transmit_energy1

Function: transmit_energy

Input constraint: store_information

Output constraint: transform_information

Name: transmit_energy2

Function: transmit_energy

Input constraint: None

Output constraint: None

Name: transmit_energy3

Function: transmit_energy

Input constraint: None

Output constraint: split_energy_with_information

Name: transmit_energy4

Function: transmit_energy

Input constraint: None

Output constraint: transform_material

Name: transmit_energy5

Function: transmit_energy

Input constraint: combine_energy_with_energy

Output constraint: None

Name: transmit_energy6

Function: transmit_energy

Input constraint: combine_energy_with_material

Output constraint: split_energy_with_information

Name: transmit_energy7

Function: transmit_energy

Input constraint: transmit_material

Output constraint: split_energy_with_energy

Name: transmit_energy8

Function: transmit_energy

Input constraint: store_information

Output constraint: store_material

Name: transmit_energy9

Function: transmit_energy

Input constraint: None

Output constraint: shape_information

Name: transmit_energy10

Function: transmit_energy

Input constraint: None

Output constraint: split_energy_with_material

Name: shape_energy1

Function: shape_energy

Input constraint: None

Output constraint: transform_material

Name: shape_energy2

Function: shape_energy

Input constraint: combine_energy_with_material

Output constraint: store_information

Name: shape_energy3

Function: shape_energy

Input constraint: shape_information

Output constraint: transmit_material

Name: shape_energy4

Function: shape_energy

Input constraint: store_material

Output constraint: transmit_material

Name: shape_energy5

Function: shape_energy

Input constraint: combine_energy_with_energy

Output constraint: transform_material

Name: shape_energy6

Function: shape_energy

Input constraint: store_information

Output constraint: split_energy_with_information

Name: shape_energy7

Function: shape_energy

Input constraint: None

Output constraint: shape_information

Name: shape_energy8

Function: shape_energy

Input constraint: shape_information

Output constraint: None

Name: shape_energy9

Function: shape_energy

Input constraint: transform_information

Output constraint: transform_information

Name: shape_energy10

Function: shape_energy

Input constraint: store_information

Output constraint: split_energy_with_information

Name: transform_energy1

Function: transform_energy

Input constraint: combine_energy_with_material

Output constraint: transform_information

Name: transform_energy2

Function: transform_energy

Input constraint: None

Output constraint: store_information

Name: transform_energy3

Function: transform_energy

Input constraint: shape_material

Output constraint: shape_material

Name: transform_energy4

Function: transform_energy

Input constraint: None

Output constraint: shape_material

Name: transform_energy5

Function: transform_energy

Input constraint: None

Output constraint: shape_material

Name: transform_energy6

Function: transform_energy

Input constraint: shape_information

Output constraint: shape_information

Name: transform_energy7

Function: transform_energy

Input constraint: combine_energy_with_information

Output constraint: transform_material

Name: transform_energy8

Function: transform_energy

Input constraint: None

Output constraint: transmit_information

Name: transform_energy9

Function: transform_energy

Input constraint: store_material

Output constraint: store_material

Name: transform_energy10

Function: transform_energy

Input constraint: None

Output constraint: split_energy_with_energy

Name: split_energy_with_energy1

Function: split_energy_with_energy

Input constraint: None

Output constraint: None

Name: split_energy_with_energy2

Function: split_energy_with_energy

Input constraint: combine_energy_with_information

Output constraint: transmit_information

Name: split_energy_with_energy3

Function: split_energy_with_energy

Input constraint: store_information

Output constraint: transmit_information

Name: split_energy_with_energy4

Function: split_energy_with_energy

Input constraint: store_information

Output constraint: shape_information

Name: split_energy_with_energy5

Function: split_energy_with_energy

Input constraint: combine_energy_with_information

Output constraint: store_information

Name: split_energy_with_energy6

Function: split_energy_with_energy

Input constraint: store_material

Output constraint: split_energy_with_material

Name: split_energy_with_energy7

Function: split_energy_with_energy

Input constraint: None

Output constraint: split_energy_with_material

Name: split_energy_with_energy8

Function: split_energy_with_energy

Input constraint: transmit_information

Output constraint: None

Name: split_energy_with_energy9

Function: split_energy_with_energy

Input constraint: None

Output constraint: split_energy_with_information

Name: split_energy_with_energy10

Function: split_energy_with_energy

Input constraint: combine_energy_with_material

Output constraint: split_energy_with_material

Name: split_energy_with_material1

Function: split_energy_with_material

Input constraint: transform_material

Output constraint: shape_material

Name: split_energy_with_material2

Function: split_energy_with_material

Input constraint: transform_information

Output constraint: shape_material

Name: split_energy_with_material3

Function: split_energy_with_material

Input constraint: combine_energy_with_information

Output constraint: store_information

Name: split_energy_with_material4

Function: split_energy_with_material

Input constraint: shape_information

Output constraint: None

Name: split_energy_with_material5

Function: split_energy_with_material

Input constraint: shape_material

Output constraint: store_information

Name: split_energy_with_material6

Function: split_energy_with_material

Input constraint: transmit_material

Output constraint: store_information

Name: split_energy_with_material7

Function: split_energy_with_material

Input constraint: combine_energy_with_information

Output constraint: store_material

Name: split_energy_with_material8

Function: split_energy_with_material

Input constraint: store_information

Output constraint: transmit_information

Name: split_energy_with_material9

Function: split_energy_with_material

Input constraint: None

Output constraint: shape_information

Name: split_energy_with_material10

Function: split_energy_with_material

Input constraint: transform_information

Output constraint: None

Name: split_energy_with_information1

Function: split_energy_with_information

Input constraint: store_information

Output constraint: split_energy_with_energy

Name: split_energy_with_information2

Function: split_energy_with_information

Input constraint: combine_energy_with_information

Output constraint: shape_information

Name: split_energy_with_information3

Function: split_energy_with_information

Input constraint: None

Output constraint: split_energy_with_material

Name: split_energy_with_information4

Function: split_energy_with_information

Input constraint: combine_energy_with_material

Output constraint: None

Name: split_energy_with_information5

Function: split_energy_with_information

Input constraint: None

Output constraint: split_energy_with_energy

Name: split_energy_with_information6

Function: split_energy_with_information

Input constraint: None

Output constraint: shape_material

Name: split_energy_with_information7

Function: split_energy_with_information

Input constraint: shape_information

Output constraint: split_energy_with_material

Name: split_energy_with_information8

Function: split_energy_with_information

Input constraint: store_information

Output constraint: transmit_material

Name: split_energy_with_information9

Function: split_energy_with_information

Input constraint: None

Output constraint: None

Name: split_energy_with_information10

Function: split_energy_with_information

Input constraint: None

Output constraint: transmit_information

Name: combine_energy_with_energy1

Function: combine_energy_with_energy

Input constraint: transform_information

Output constraint: shape_information

Name: combine_energy_with_energy2

Function: combine_energy_with_energy

Input constraint: shape_material

Output constraint: transmit_material

Name: combine_energy_with_energy3

Function: combine_energy_with_energy

Input constraint: combine_energy_with_information

Output constraint: shape_material

Name: combine_energy_with_energy4

Function: combine_energy_with_energy

Input constraint: None

Output constraint: None

Name: combine_energy_with_energy5

Function: combine_energy_with_energy

Input constraint: None

Output constraint: store_information

Name: combine_energy_with_energy6

Function: combine_energy_with_energy

Input constraint: shape_material

Output constraint: split_energy_with_material

Name: combine_energy_with_energy7

Function: combine_energy_with_energy

Input constraint: transmit_material

Output constraint: transmit_material

Name: combine_energy_with_energy8

Function: combine_energy_with_energy

Input constraint: None

Output constraint: None

Name: combine_energy_with_energy9

Function: combine_energy_with_energy

Input constraint: None

Output constraint: split_energy_with_energy

Name: combine_energy_with_energy10

Function: combine_energy_with_energy

Input constraint: None

Output constraint: transmit_material

Name: combine_energy_with_material1

Function: combine_energy_with_material

Input constraint: store_material

Output constraint: split_energy_with_information

Name: combine_energy_with_material2

Function: combine_energy_with_material

Input constraint: None

Output constraint: None

Name: combine_energy_with_material3

Function: combine_energy_with_material

Input constraint: transform_material

Output constraint: shape_information

Name: combine_energy_with_material4

Function: combine_energy_with_material

Input constraint: store_information

Output constraint: split_energy_with_material

Name: combine_energy_with_material5

Function: combine_energy_with_material

Input constraint: transform_information

Output constraint: split_energy_with_material

Name: combine_energy_with_material6

Function: combine_energy_with_material

Input constraint: None

Output constraint: transmit_material

Name: combine_energy_with_material7

Function: combine_energy_with_material

Input constraint: combine_energy_with_energy

Output constraint: split_energy_with_energy

Name: combine_energy_with_material8

Function: combine_energy_with_material

Input constraint: combine_energy_with_information

Output constraint: transform_information

Name: combine_energy_with_material9

Function: combine_energy_with_material

Input constraint: store_material

Output constraint: shape_material

Name: combine_energy_with_material10

Function: combine_energy_with_material

Input constraint: None

Output constraint: transform_information

Name: combine_energy_with_information1

Function: combine_energy_with_information

Input constraint: None

Output constraint: transform_information

Name: combine_energy_with_information2

Function: combine_energy_with_information

Input constraint: combine_energy_with_material

Output constraint: shape_information

Name: combine_energy_with_information3

Function: combine_energy_with_information

Input constraint: shape_information

Output constraint: None

Name: combine_energy_with_information4

Function: combine_energy_with_information

Input constraint: combine_energy_with_material

Output constraint: transform_information

Name: combine_energy_with_information5

Function: combine_energy_with_information

Input constraint: shape_material

Output constraint: None

Name: combine_energy_with_information6

Function: combine_energy_with_information

Input constraint: None

Output constraint: split_energy_with_energy

Name: combine_energy_with_information7

Function: combine_energy_with_information

Input constraint: transform_material

Output constraint: split_energy_with_information

Name: combine_energy_with_information8

Function: combine_energy_with_information

Input constraint: None

Output constraint: None

Name: combine_energy_with_information9

Function: combine_energy_with_information

Input constraint: transmit_material

Output constraint: None

Name: combine_energy_with_information10

Function: combine_energy_with_information

Input constraint: combine_energy_with_energy

Output constraint: shape_material

Name: store_information1

Function: store_information

Input constraint: combine_information_with_information

Output constraint: shape_energy

Name: store_information2

Function: store_information

Input constraint: None

Output constraint: None

Name: store_information3

Function: store_information

Input constraint: None

Output constraint: split_information_with_energy

Name: store_information4

Function: store_information

Input constraint: store_material

Output constraint: split_information_with_material

Name: store_information5

Function: store_information

Input constraint: store_energy

Output constraint: transmit_energy

Name: store_information6

Function: store_information

Input constraint: None

Output constraint: None

Name: store_information7

Function: store_information

Input constraint: transform_energy

Output constraint: transform_material

Name: store_information8

Function: store_information

Input constraint: combine_information_with_information

Output constraint: split_information_with_energy

Name: store_information9

Function: store_information

Input constraint: transmit_material

Output constraint: store_material

Name: store_information10

Function: store_information

Input constraint: combine_information_with_energy

Output constraint: None

Name: transmit_information1

Function: transmit_information

Input constraint: None

Output constraint: None

Name: transmit_information2

Function: transmit_information

Input constraint: store_material

Output constraint: transmit_material

Name: transmit_information3

Function: transmit_information

Input constraint: transmit_energy

Output constraint: split_information_with_information

Name: transmit_information4

Function: transmit_information

Input constraint: None

Output constraint: None

Name: transmit_information5

Function: transmit_information

Input constraint: transform_material

Output constraint: None

Name: transmit_information6

Function: transmit_information

Input constraint: shape_energy

Output constraint: split_information_with_material

Name: transmit_information7

Function: transmit_information

Input constraint: None

Output constraint: split_information_with_information

Name: transmit_information8

Function: transmit_information

Input constraint: combine_information_with_energy

Output constraint: transmit_energy

Name: transmit_information9

Function: transmit_information

Input constraint: shape_energy

Output constraint: transform_material

Name: transmit_information10

Function: transmit_information

Input constraint: transmit_material

Output constraint: transmit_energy

Name: shape_information1

Function: shape_information

Input constraint: combine_information_with_material

Output constraint: split_information_with_information

Name: shape_information2

Function: shape_information

Input constraint: combine_information_with_information

Output constraint: shape_energy

Name: shape_information3

Function: shape_information

Input constraint: None

Output constraint: None

Name: shape_information4

Function: shape_information

Input constraint: combine_information_with_material

Output constraint: None

Name: shape_information5

Function: shape_information

Input constraint: transmit_energy

Output constraint: transmit_material

Name: shape_information6

Function: shape_information

Input constraint: transmit_energy

Output constraint: None

Name: shape_information7

Function: shape_information

Input constraint: shape_material

Output constraint: store_material

Name: shape_information8

Function: shape_information

Input constraint: None

Output constraint: transmit_material

Name: shape_information9

Function: shape_information

Input constraint: None

Output constraint: split_information_with_energy

Name: shape_information10

Function: shape_information

Input constraint: None

Output constraint: transmit_material

Name: transform_information1

Function: transform_information

Input constraint: None

Output constraint: shape_material

Name: transform_information2

Function: transform_information

Input constraint: combine_information_with_energy

Output constraint: shape_energy

Name: transform_information3

Function: transform_information

Input constraint: transmit_energy

Output constraint: transform_energy

Name: transform_information4

Function: transform_information

Input constraint: combine_information_with_material

Output constraint: shape_material

Name: transform_information5

Function: transform_information

Input constraint: combine_information_with_information

Output constraint: transmit_material

Name: transform_information6

Function: transform_information

Input constraint: None

Output constraint: transform_energy

Name: transform_information7

Function: transform_information

Input constraint: transform_energy

Output constraint: None

Name: transform_information8

Function: transform_information

Input constraint: transform_material

Output constraint: None

Name: transform_information9

Function: transform_information

Input constraint: None

Output constraint: None

Name: transform_information10

Function: transform_information

Input constraint: transform_energy

Output constraint: None

Name: split_information_with_information1

Function: split_information_with_information

Input constraint: combine_information_with_energy

Output constraint: split_information_with_material

Name: split_information_with_information2

Function: split_information_with_information

Input constraint: transmit_energy

Output constraint: split_information_with_energy

Name: split_information_with_information3

Function: split_information_with_information

Input constraint: None

Output constraint: None

Name: split_information_with_information4

Function: split_information_with_information

Input constraint: store_energy

Output constraint: split_information_with_material

Name: split_information_with_information5

Function: split_information_with_information

Input constraint: None

Output constraint: split_information_with_energy

Name: split_information_with_information6

Function: split_information_with_information

Input constraint: None

Output constraint: None

Name: split_information_with_information7

Function: split_information_with_information

Input constraint: None

Output constraint: transmit_material

Name: split_information_with_information8

Function: split_information_with_information

Input constraint: None

Output constraint: store_material

Name: split_information_with_information9

Function: split_information_with_information

Input constraint: store_material

Output constraint: store_material

Name: split_information_with_information10

Function: split_information_with_information

Input constraint: combine_information_with_information

Output constraint: transmit_material

Name: split_information_with_material1

Function: split_information_with_material

Input constraint: None

Output constraint: split_information_with_information

Name: split_information_with_material2

Function: split_information_with_material

Input constraint: None

Output constraint: None

Name: split_information_with_material3

Function: split_information_with_material

Input constraint: transmit_material

Output constraint: split_information_with_energy

Name: split_information_with_material4

Function: split_information_with_material

Input constraint: combine_information_with_energy

Output constraint: None

Name: split_information_with_material5

Function: split_information_with_material

Input constraint: None

Output constraint: transform_energy

Name: split_information_with_material6

Function: split_information_with_material

Input constraint: combine_information_with_energy

Output constraint: transmit_energy

Name: split_information_with_material7

Function: split_information_with_material

Input constraint: transmit_energy

Output constraint: None

Name: split_information_with_material8

Function: split_information_with_material

Input constraint: shape_energy

Output constraint: None

Name: split_information_with_material9

Function: split_information_with_material

Input constraint: transform_energy

Output constraint: shape_material

Name: split_information_with_material10

Function: split_information_with_material

Input constraint: transmit_energy

Output constraint: None

Name: split_information_with_energy1

Function: split_information_with_energy

Input constraint: transmit_material

Output constraint: transform_energy

Name: split_information_with_energy2

Function: split_information_with_energy

Input constraint: transmit_material

Output constraint: shape_material

Name: split_information_with_energy3

Function: split_information_with_energy

Input constraint: store_energy

Output constraint: None

Name: split_information_with_energy4

Function: split_information_with_energy

Input constraint: None

Output constraint: split_information_with_information

Name: split_information_with_energy5

Function: split_information_with_energy

Input constraint: store_material

Output constraint: store_energy

Name: split_information_with_energy6

Function: split_information_with_energy

Input constraint: None

Output constraint: transmit_material

Name: split_information_with_energy7

Function: split_information_with_energy

Input constraint: transform_energy

Output constraint: transform_material

Name: split_information_with_energy8

Function: split_information_with_energy

Input constraint: None

Output constraint: store_energy

Name: split_information_with_energy9

Function: split_information_with_energy

Input constraint: None

Output constraint: transmit_material

Name: split_information_with_energy10

Function: split_information_with_energy

Input constraint: None

Output constraint: transmit_material

Name: combine_information_with_information1

Function: combine_information_with_information

Input constraint: combine_information_with_material

Output constraint: split_information_with_material

Name: combine_information_with_information2

Function: combine_information_with_information

Input constraint: transform_material

Output constraint: store_material

Name: combine_information_with_information3

Function: combine_information_with_information

Input constraint: shape_material

Output constraint: shape_material

Name: combine_information_with_information4

Function: combine_information_with_information

Input constraint: combine_information_with_energy

Output constraint: None

Name: combine_information_with_information5

Function: combine_information_with_information

Input constraint: transform_material

Output constraint: transmit_energy

Name: combine_information_with_information6

Function: combine_information_with_information

Input constraint: store_energy

Output constraint: shape_energy

Name: combine_information_with_information7

Function: combine_information_with_information

Input constraint: combine_information_with_energy

Output constraint: split_information_with_information

Name: combine_information_with_information8

Function: combine_information_with_information

Input constraint: store_material

Output constraint: split_information_with_material

Name: combine_information_with_information9

Function: combine_information_with_information

Input constraint: None

Output constraint: split_information_with_energy

Name: combine_information_with_information10

Function: combine_information_with_information

Input constraint: None

Output constraint: None

Name: combine_information_with_material1

Function: combine_information_with_material

Input constraint: transform_energy

Output constraint: transform_energy

Name: combine_information_with_material2

Function: combine_information_with_material

Input constraint: combine_information_with_information

Output constraint: transform_energy

Name: combine_information_with_material3

Function: combine_information_with_material

Input constraint: None

Output constraint: split_information_with_information

Name: combine_information_with_material4

Function: combine_information_with_material

Input constraint: store_material

Output constraint: transform_material

Name: combine_information_with_material5

Function: combine_information_with_material

Input constraint: shape_material

Output constraint: store_energy

Name: combine_information_with_material6

Function: combine_information_with_material

Input constraint: transform_material

Output constraint: store_material

Name: combine_information_with_material7

Function: combine_information_with_material

Input constraint: None

Output constraint: split_information_with_information

Name: combine_information_with_material8

Function: combine_information_with_material

Input constraint: transform_energy

Output constraint: transmit_energy

Name: combine_information_with_material9

Function: combine_information_with_material

Input constraint: transmit_material

Output constraint: store_material

Name: combine_information_with_material10

Function: combine_information_with_material

Input constraint: combine_information_with_energy

Output constraint: transmit_material

Name: combine_information_with_energy1

Function: combine_information_with_energy

Input constraint: transform_material

Output constraint: None

Name: combine_information_with_energy2

Function: combine_information_with_energy

Input constraint: None

Output constraint: transmit_energy

Name: combine_information_with_energy3

Function: combine_information_with_energy

Input constraint: None

Output constraint: split_information_with_material

Name: combine_information_with_energy4

Function: combine_information_with_energy

Input constraint: transmit_energy

Output constraint: split_information_with_material

Name: combine_information_with_energy5

Function: combine_information_with_energy

Input constraint: transform_material

Output constraint: store_energy

Name: combine_information_with_energy6

Function: combine_information_with_energy

Input constraint: store_energy

Output constraint: None

Name: combine_information_with_energy7

Function: combine_information_with_energy

Input constraint: None

Output constraint: split_information_with_information

Name: combine_information_with_energy8

Function: combine_information_with_energy

Input constraint: transform_material

Output constraint: None

Name: combine_information_with_energy9

Function: combine_information_with_energy

Input constraint: combine_information_with_information

Output constraint: None

Name: combine_information_with_energy10

Function: combine_information_with_energy

Input constraint: transform_material

Output constraint: None

### expected answer:

| Node | Entity | Predecessors | Successors | Covered By |
|---|---|---|---|---|
| store_material_1 | material | | store_material_5 | store_material1 |
| store_energy_2 | energy | | combine_energy_with_material_6 | store_energy1 |
| store_information_4 | information | | combine_information_with_information_10 | store_information6 |
| store_material_5 | material | store_material_1 | combine_energy_with_material_6 | store_material10 |
| combine_energy_with_material_6 | energy | store_energy_2 store_material_5 | | combine_energy_with_material2 |
| transmit_energy_8 | energy | | | store_material1 |
| transmit_information_9 | information | | combine_information_with_information_10 | store_energy1 |
| combine_information_with_information_10 | information | store_information_4 transmit_information_9 | | combine_information_with_information10 |
| store_energy_11 | energy | | | store_energy1 |
| transmit_information_12 | information | | | store_energy1 |

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## Question 10 (GPT4o)

In the development of a portable cooling device, a design proposal suggests eliminating all active components (such as fans or compressors) and relying entirely on passive thermal regulation using phase-change materials. The intended product must operate effectively in a wide range of climates and maintain a target temperature for several hours during use. Would this design decision be feasible and optimal given the requirements?

### expected answer:

Feasible but not optimal.

---

## Question 11

A design team is developing a lightweight, disposable life rescue tool for emergency situations (e.g. cutting seat belts, breaking windows). One proposal is to manufacture key structural components from titanium instead of the current plastic composite, in order to improve heat resistance. However, the product is intended for single use. Would this change likely lead to a more optimal product design?

### expected answer:

Human Life is more important than cost efficiency.

## Question 12 (GPT4o)

An engineer proposes replacing the aluminum casing of a high-power electronic device with a polymer-based composite to reduce weight and improve electrical insulation. The device is intended to operate continuously at high current in a compact enclosure with minimal ventilation. According to the engineer, the composite also simplifies manufacturing due to injection molding compatibility. Would this material change likely result in a better overall design?

### expected answer:

Problem of thermal management.

---

## Question 13

Below is a function structure representing the core operations of a bicycle. Why are the store_information and transmit_information functions positioned upstream of energy or material transformations in multiple places within this structure?

store_energy_1 → transmit_energy_2

transmit_energy_2 → transform_energy_3

transform_energy_3 → transmit_energy_4

transmit_energy_4 → transform_energy_5

store_material_6 → transform_material_7

transform_material_7 → transmit_material_8

store_information_9 → transmit_information_10

store_energy_10a → combine_energy_with_information_11

transmit_information_10 → combine_energy_with_information_11

combine_energy_with_information_11 → transform_energy_12

transform_energy_12 → store_energy_13

store_information_14 → transmit_information_15

store_material_15a → combine_material_with_information_16

transmit_information_15 → combine_material_with_information_16

combine_material_with_information_16 → transform_material_17

store_energy_18 → transform_energy_19

transform_energy_19 → transmit_energy_20

transmit_energy_20 → transform_energy_21

transform_energy_21 → split_energy_with_information_22

split_energy_with_information_22 → transmit_information_23

split_energy_with_information_22 → transmit_energy_24

store_information_25 → transmit_information_26

transmit_information_26 → transform_information_27

### expected answer:
Gear shifting purposes.

---

## Question 14 (GPT4o)
In a function structure, a segment includes the following sequence:

split_material_with_information_1 → transmit_material_2

split_material_with_information_1 → transmit_information_3

transmit_material_2 → combine_energy_with_material_4

transmit_information_3 → combine_information_with_material_5

combine_energy_with_material_4 → transform_material_6

combine_information_with_material_5 → transform_material_6

Why is a split_material_with_information function used that is followed by separate material and information transmission paths, only to combine them again before transforming the material? What does this design suggest about the intention behind the process?

### expected answer:
Modularity

---

## Question 15
In a product design, the following section of a function structure is realized using four separate Solution Principles—each one covering a single function:

store_energy_1 → transmit_energy_2

transmit_energy_2 → combine_energy_with_material_3

combine_energy_with_material_3 → transform_material_4

In the Solution Principle catalog, there also exists an alternative Solution Principle that fulfills combine_energy_with_material and lists transform_material as an output constraint. Why might the designer have chosen the approach with four separate Solution Principles instead of using the one that combines two functions?

### expected answer:
Modularity

---

## Question 16 (GPT4o)

In a product concept, a Solution Principle for the function transform_material was chosen that requires an additional combine_material_with_material input constraint. However, the Solution Principle catalog also includes alternatives for transform_material that do not require any constraints and appear more efficient on paper. Why was the more demanding Solution Principle selected to fulfill the function?

### expected answer:

It fits better with other functions in the structure.

---

## Question 17

Below is a function structure intended to represent the core operations of a human-powered bicycle:

store_energy_1 → transmit_energy_2

transmit_energy_2 → transform_energy_3

transform_energy_3 → transmit_energy_4

transmit_energy_4 → transform_energy_5

store_material_6 → shape_material_7

shape_material_7 → transmit_material_8

store_information_9 → transmit_information_10

transmit_information_10 → transform_energy_11

transform_energy_11 → store_energy_12

store_information_13 → transmit_information_14

transmit_information_14 → transform_material_15

store_energy_16 → transform_energy_17

transform_energy_17 → transmit_energy_18

transmit_energy_18 → transform_energy_19

transform_energy_19 → transmit_information_20

store_information_21 → transmit_information_22

transmit_information_22 → transform_information_23

Is this function structure feasible? Justify your answer.

### expected answer:

No, wrong entity connections.

---

## Question 18 (GPT4o)

Below is a function structure representing the core operations of a bicycle. Why is this function structure not feasible?

store_energy_1 → transmit_energy_2

transmit_energy_2 → transform_energy_3

transform_energy_3 → transmit_energy_4

transmit_energy_4 → transform_energy_5

store_material_6 → transform_material_7

transform_material_7 → transmit_material_8

store_information_9 → transmit_information_10

store_energy_10a → combine_energy_with_information_11

transmit_information_10 → combine_energy_with_information_11

combine_energy_with_information_11 → transform_energy_12

transform_energy_12 → store_energy_13

store_information_14 → transmit_information_15

store_material_15a → combine_material_with_information_16

transmit_information_15 → combine_material_with_information_16

combine_material_with_information_16 → transform_material_17

store_energy_18 → transform_energy_19

transform_energy_19 → transmit_energy_20

transmit_energy_20 → transform_energy_21

transform_energy_21 → split_energy_with_information_22

split_energy_with_information_22 → transmit_information_23

split_energy_with_information_22 → transmit_energy_24

store_information_25 → transmit_information_26

transmit_information_26 → transform_information_27

### expected answer:

It is feasible!

---

## Question 19

You are given the following 30 Roth functions, categorized by entity (material, energy, information):

Material:

store_material

transmit_material

shape_material

transform_material

split_material_with_material

split_material_with_energy

split_material_with_information

combine_material_with_material

combine_material_with_energy

combine_material_with_information

Energy:

store_energy

transmit_energy

shape_energy

transform_energy

split_energy_with_energy

split_energy_with_material

split_energy_with_information

combine_energy_with_energy

combine_energy_with_material

combine_energy_with_information

Information:

store_information

transmit_information

shape_information

transform_information

split_information_with_information

split_information_with_material

split_information_with_energy

combine_information_with_information

combine_information_with_material

combine_information_with_energy

Using the Roth functions listed above, infer a function structure that represents a time travel device. The structure should identify the functions involved, their associated entities, and how they are connected, such that it reflects the internal functional decomposition of the time travel device.

### expected answer:

It is simply not possible to have a working function structure for a time travel device. Time is not an entity that can be manipulated in any way.

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## Question 20 (GPT4o)

A solution principle for assistance in a bicycle is a typical 250 watts electric motor. However, questioning customers has shown that there is a demand for higher assistance. Is it viable to integrate a 6kW electric motor into the next iteration of bicycle increasing the price only marginally by about 10%?

### expected answer:

No, the motor would be much too heavy.