187.A27 VU **Design Studies**

8-10. Ingenieurwiss. u. kognitiver Ansatz

Descriptive Design Research

- empirische Untersuchung – Designexperiment
- Untersuchungsergebnisse

- Analysing (video-recorded) designing
- Protocol Analysis
- FBS ontology
  - UE: FBS – coding
  - LINKODER

FBS ontology

John Gero, et.al.

Design & Designing

Design exists because the world around us does not suit us, and the goal of designers is to change the world through the creation of artifacts.

Designers are change agents in society.

Their goal is to improve the human condition in all its aspects through physical change.

Design is one of the profound activities of humans.

(Gero John: Design Prototypes: A Knowledge Representation Schema for Design. AI Magazine Vol 11 Nr 4 (1990) AAAI).

Design research

goals:

- a better understanding of design,
- the development of tools to aid human designers,
- the potential automation of some design tasks.

Gero, 1990: Design Prototypes

Design & Designing

Axiom:

"The foundations of designing are independent of the designer, their situation and what is being designed."

↳ "implies that the differences between design professions and design practices are not foundational to designing notwithstanding the apparent differences …"

↳ **all designs** and **all designing** could be represented in a uniform way as

a set of irreducible **foundational concepts** of design and designing

Gero & Kannengiesser 2013: The Function-Behaviour-Structure Ontology of Design. p. 2

ontology … an explicit specification of a conceptualization.

Knowledge of a domain is represented in a declarative formalism in terms of a set of objects and their relationships.

ontology ≈ the framework for the knowledge in a field.

design ontology - defining the representational terms - **design issues** - and their relationships

Kan, Gero & Sarkar 2010: Using a Generic Method to Study Software Design Cognition

Designers design by positing functions to be achieved and producing descriptions of artifacts capable of generating these functions. (p 27)

In this sense, design is the opposite of the traditional scientific explanation.

Thus, design is purposeful, and the activity of designing is goal oriented.

The meta**goal of design** is to **transform requirements**, generally termed **functions**, which embody the expectations of the purposes of the resulting artifact, **into design descriptions**.

The result of the activity of designing is a design description (p 28)

Protocol analysis

1. Coding development
2. Recording verbalisations/activities of designers
3. Transcribing the recordings
4. Segmenting and coding the transcriptions
5. Analysing the coded protocols
6. Generating the conceptual links
7. Analysing the linkograph

Pourmohamadi & Gero: LINKOgrapher: An Analysis Tool To Study Design Protocols Based On FBS Coding Scheme. ICED11.

“The ad-hoc nature of traditional protocol studies limits their use to the specific cases they have been developed for. Even the results of different studies over a single data set are not comparable in many cases”

Pourmohamadi & Gero: LINKOgrapher: An Analysis Tool To Study Design Protocols Based On FBS Coding Scheme. ICED11.

Models of Design

The purpose of **designing is to transform function F** (F is a set) **into a design description D** in such a way that the artifact being described is capable of producing these functions.

Bs: designing windows

some functions **F**
- provision of daylight,
- control of ventilation,
- access to a view.

➔ **D** design description;
(sketches, drawings, etc.)

Thus, a naive model of design is

F ➔ D

➔ … is some transformation

There is, however, **no direct transformation** capable of achieving this result.

Models of Design

~~F → D~~

D … **design description** represents the artifact's elements and their relationships = **structure S**.

Bs. window design

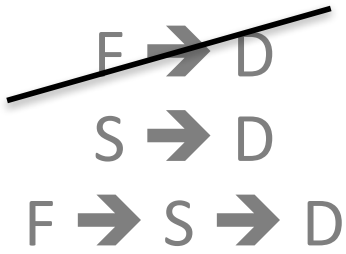
the artifact's elements are

- the glazing
- the frame and
- their topology.

structure is transformed into a design description
(e.g. sketches, drawings, CAD, models, notes, etc.)

S → D

Models of Design



Another model of design is

F → S

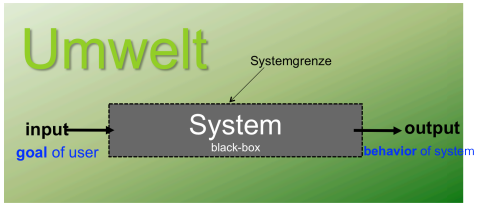
occasional transformation - direct mapping between function and structure – ‘catalog lookup’ is not considered designing.

generally, no direct transformation between function and structure exists,

↳ indirect transformation between function and structure

Models of Design

Def.: **Function F** = the **relation** between the **goal** of a human user and the **behavior** of a system.



In designing, behavior can be viewed in two ways:

1. **behavior of the structure Bs** (Bs is a set), is directly derivable from structure:

$$S \rightarrow Bs$$

analysis process

Bs: window design

the behaviors of the structure include

- light flux transmitted,
- ventilation rate,
- various solar gains.

= **analysis** process - presupposes the delineation of which behaviors to determine.

2. Transforming function to **expected behaviors Be** (Be is a set) - second view of behavior.

Bs: window design

expected behaviors include

- Light transmission,
- ventilation rates, and
- solar collection.

$$F \rightarrow Be$$

This process = **formulation** or specification in design.

Models of Design

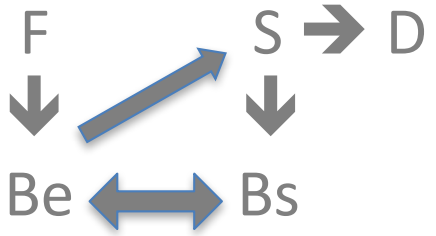
The predicted behavior of the structure Bs can be compared with the expected behavior Be required to determine if the structure synthesized is capable of producing the functions:

Be ↔ Bs

↔ … comparison

This comparison = **evaluation** process in design.

Models of Design



Another model of design is

$$\mathbf{F \longrightarrow Be}$$

$$\mathbf{Be \longrightarrow S(Bs)}$$

synthesis process

Here, the function is transformed to expected behavior.

This expected behavior is used in the selection and combination of structure based on a knowledge of the behaviors produced by this structure.

This process is called **synthesis**.

designing windows

some **functions (F)**:

- provision of daylight,
- control of ventilation,
- access to a view.

artifact's **elements (S)** are

- the glazing
- the frame and
- their topology

expected behaviors (**Be)**

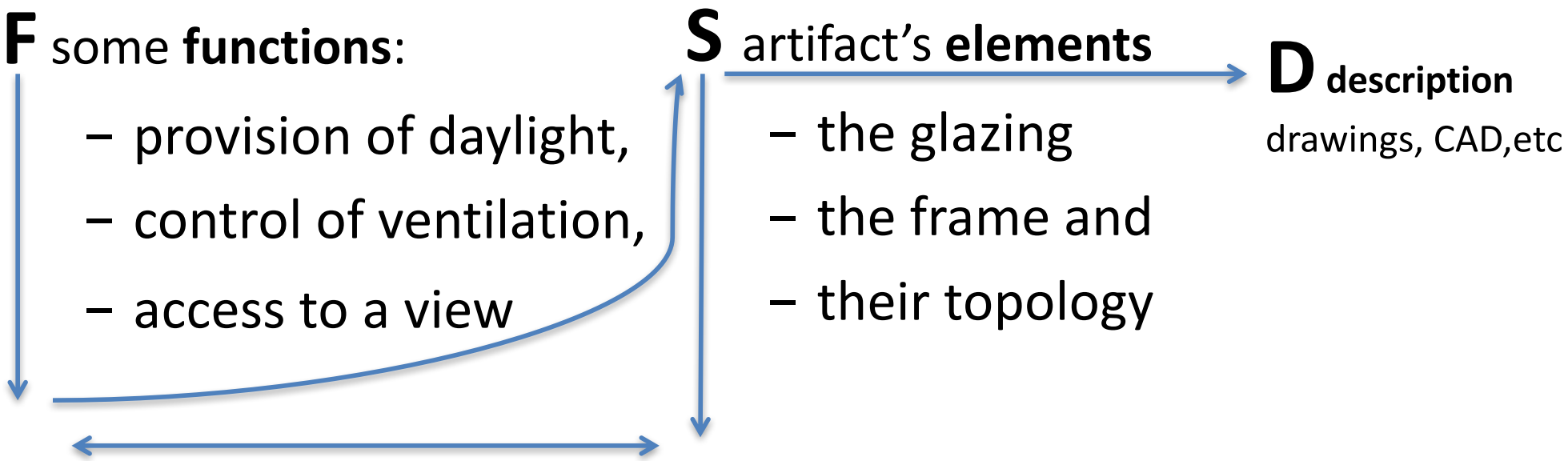
- Light transmission,
- ventilation rates, and
- solar collection.

behaviors of the structure (**Bs)**

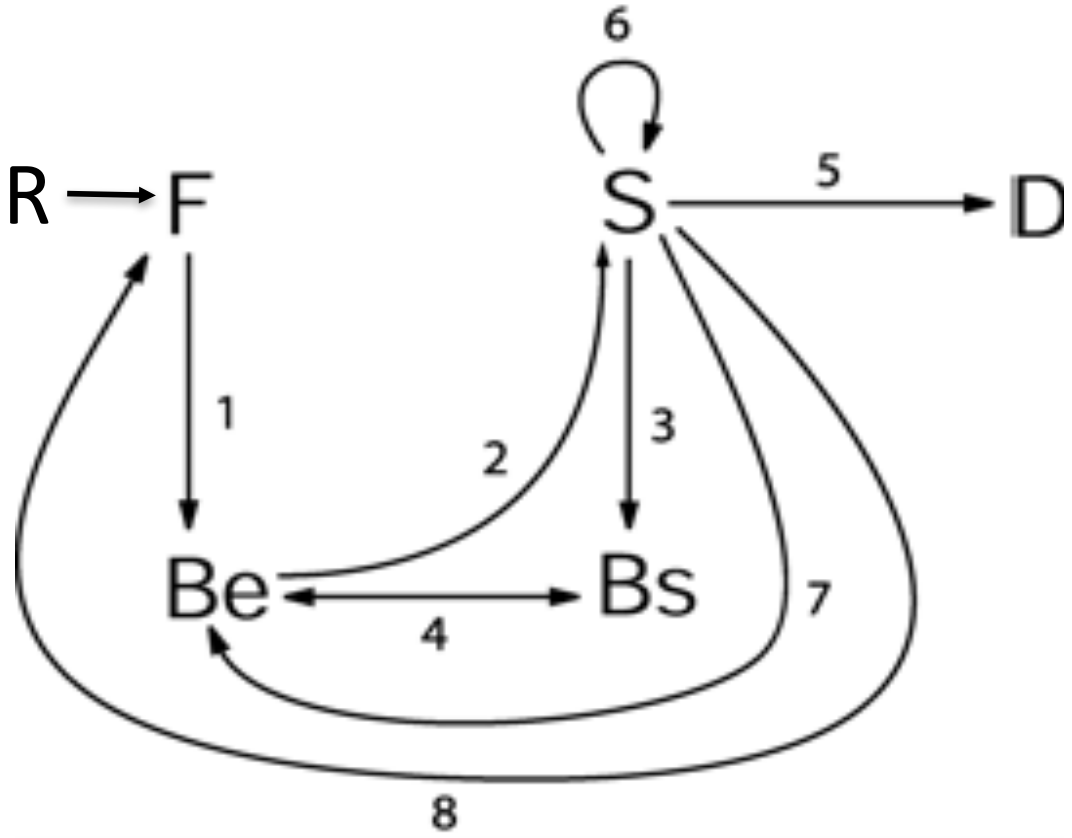
- light flux transmitted,
- ventilation rate,
- various solar gains.

design **description (D)**: drawings, notes …

designing windows



The FBS ontology of designing



R … requirements
F … function
Be … expected behaviour
Bs … behaviour derived from structure
S … structure
D … design description

→ … transformation
↔ … comparison

Gero 2010: Generalizing Design Cognition Research. DTRS8

FBS-view of Objects

FBS ontology provides three high-level categories for the properties of an object:

Function (**F**) of an object is defined as its purposes or teleology

"what the object is for"

Behaviour (**B**) of an object is defined as the attributes that are derived or expected to be derived from its structure (S);

how it achieves its functions, i.e.

"what the object does"

Behavior relates to those attributes of an entity that allow comparison on a performance level rather than on a compositional level.

Structure (**S**) of an object is defined as its components and their relationships, i.e.

"what the object consists of"

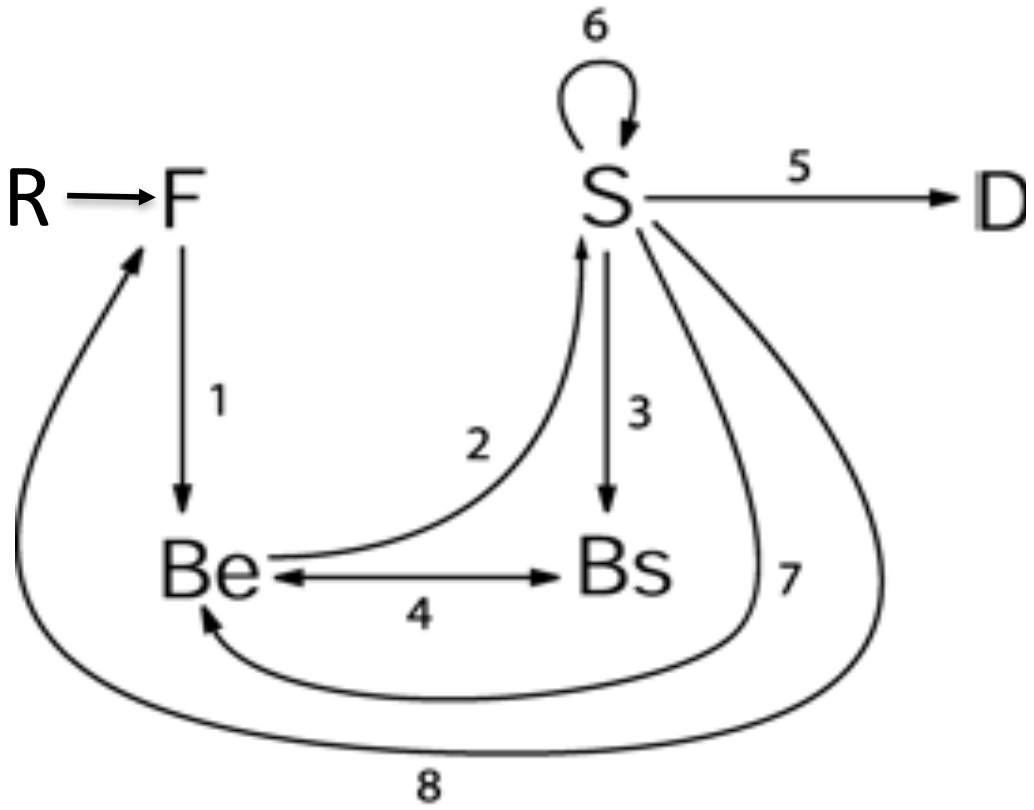
e.g. in terms of geometry, topology, material

(Gero & Kannengiesser (2007) "A function-behavior-structure ontology of processes. P 380)

Examples of function, behaviour and structure of different artefacts

	Dwelling	Editing software	Manufacturing process	Team
Function (F)	Provide safety, provide comfort, provide affordability	Be time efficient, provide affordability	Be safe, be time efficient, provide sustainability, provide affordability	Be time efficient, provide affordability
Behaviour (B)	Strength, weight, heat absorption, cost	Response times, cost	Throughput, accuracy, speed, waste rate, cost	Working speed, success rate, cost
Structure (S)	Geometrically interconnected walls, floors, roof, windows, doors, pipes, electrical systems	Computationally interconnected program components	Logically and physically interconnected operations and flows of material and information	Socially interconnected individuals

The FBS ontology of designing



R … requirements
F … function
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↔ … comparison

Code
R
F
Bs
Be
S
D

Gero 2010: Generalizing Design Cognition Research. DTRS8

FBS-Based Design Issues Protocol Coding Scheme

codes in the coding scheme are structured in accordance with the design issues defined by the FBS ontology.

codes are defined as design issues.

6 codes

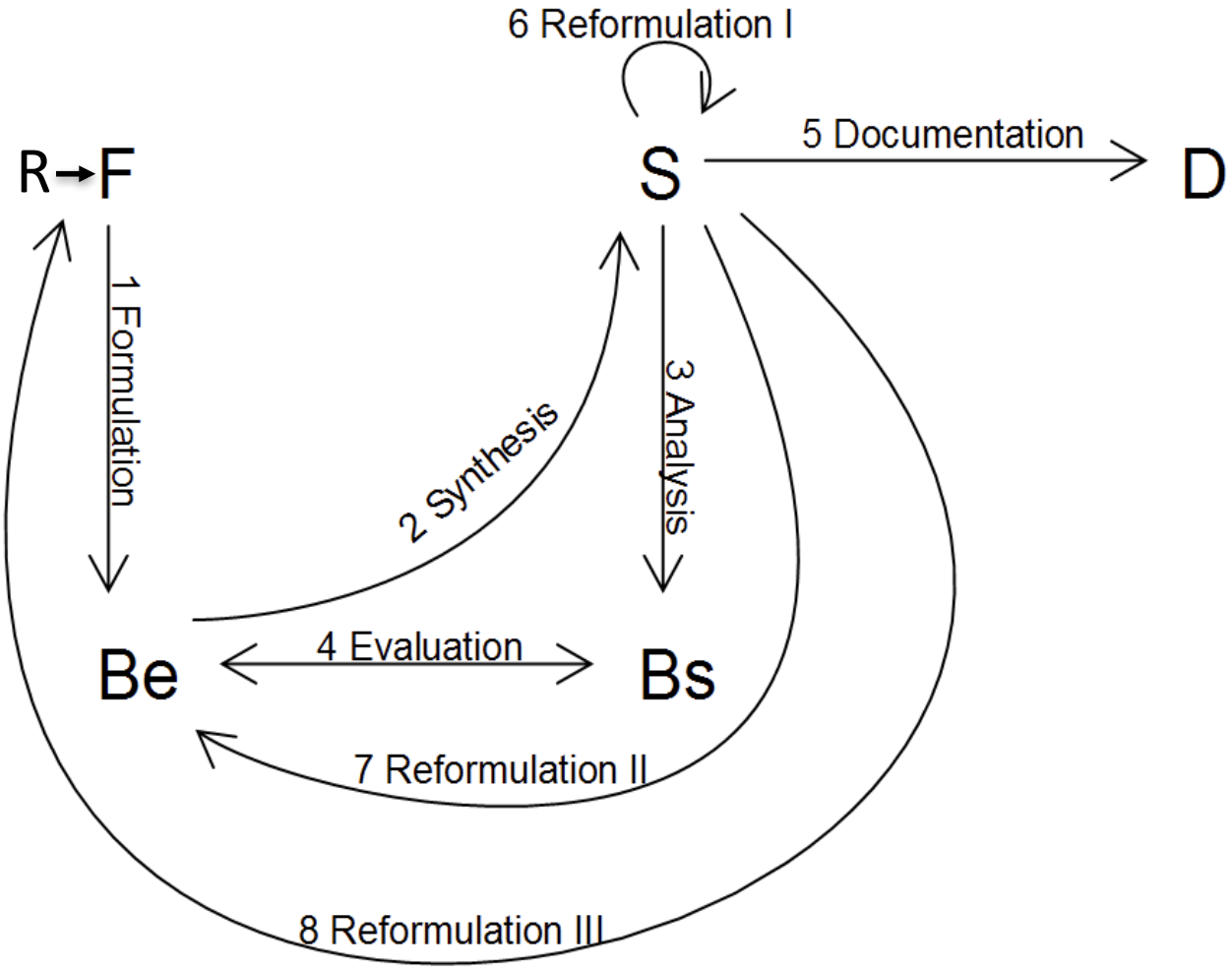
- Functions (F),
- Expected Behaviours (Be),
- Structures (S),
- Structural Behaviour (Bs), and
- Documents (D), as well as the design
- issues that arise from sources other than the designer (e.g. design brief) are coded as Requirements (R).

only one design issue for each segment = strict isomorphism between codes and segments

no overlapping codes or multi-code segments in the coded protoco

Pourmohamadi & Gero: LINKOgrapher: An Analysis Tool To Study Design Protocols Based On FBS Coding Scheme. ICED11.

The FBS ontology of designing



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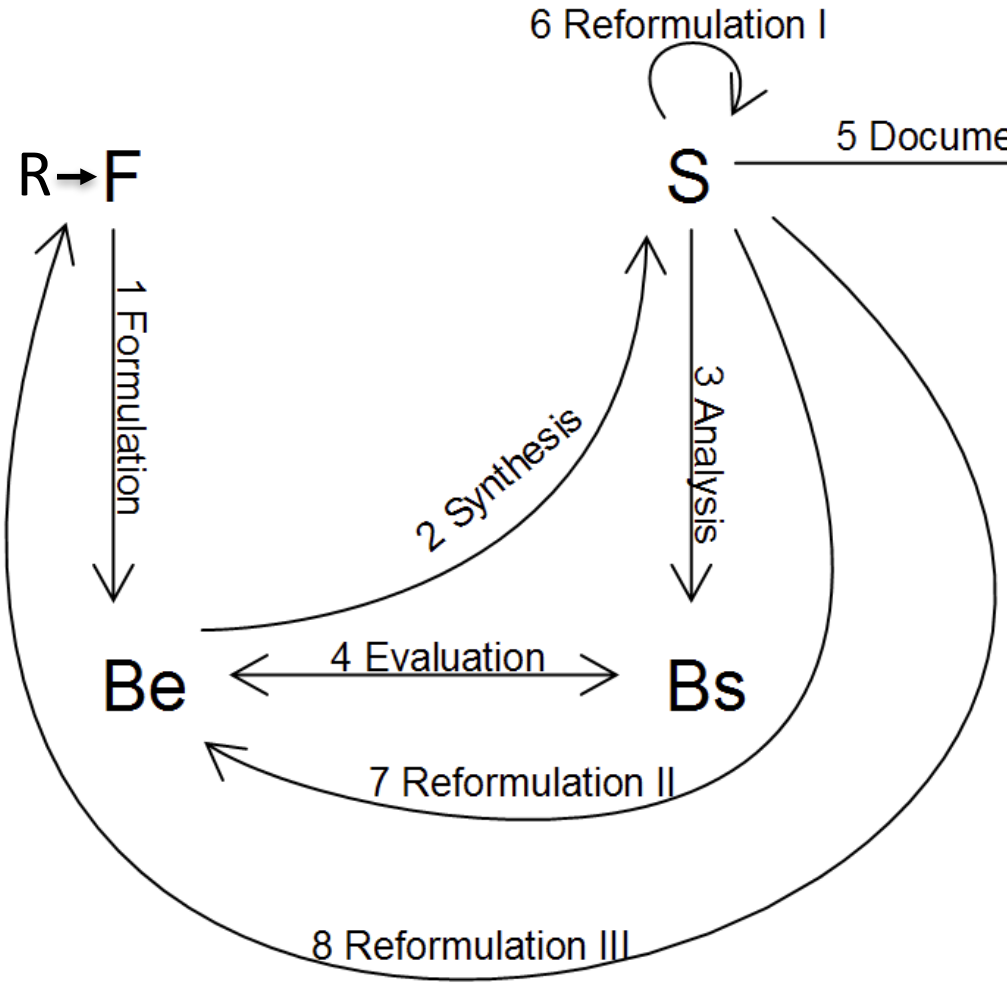
Kan & Gero: A Generic Tool to Study Human Design Activities. ICED'09/2 (p 239)

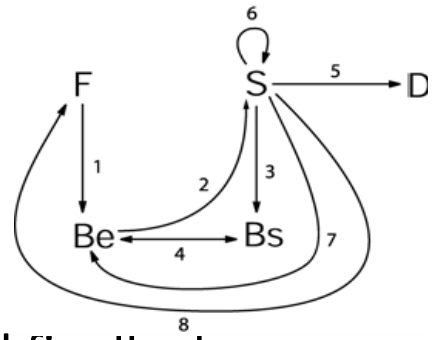
The FBS ontology of designing



Design Process	
Formulation (1)	R>F,F>Be
Synthesis (2)	Be>S
Analysis (3)	S>Bs
Documentation (5)	S>D
Evaluation (4)	Be<>Bs
Reformulation I (6)	S>S
Reformulation II (7)	S>Be
Reformulation II (8)	S>F

Kan & Gero: A Generic Tool to Study Human Design Activities. ICED'09/2 (p 239)

8 design processes



The aim of designing is to transform functions into structures and finally documen

Design processes are defined as **transition**al processes **between code pairs**.

1 **Formulation** is the process of inferring expected behaviours from the functions and requirements. **F → Be**

2 **Synthesis** is the process of transforming expected behaviours into structure. **Be → S**

3 **Analysis** is the process of transforming structure into behaviours derived from structure. **S → Bs**

4 **Evaluation** is the process of comparing analysed behaviours with expected behaviours. **Be → Bs**

5 **Documentation** is the process of external representation.

6-8 **Reformulations** are the processes of changing the space of possible designs by changing the structures, behaviours or functions. **S → S, S → Be, S → F**

Pourmohamadi & Gero: LINKOgrapher: An Analysis Tool To Study Design Protocols ICED11.

Reformulation processes

When structures are synthesized, they produce their own behaviors (Bs), which can be a useful superset of the expected behaviors.

This process **can change** the range of **expected behaviors (S → Be)** and through them the **function (S → F)** being designed for, leading to a **reformulation**.

Reformulation can also occur when the evaluation of the comparison between the behavior of the structure (Bs) and the expected behavior (Be) is unsatisfactory and cannot be made satisfactory by manipulating the structure. This reformulation leads to a change in expected behavior (Be).

processes of reformulation I, II, III

Traditional models of designing iterate the analysis – synthesis - evaluation processes until a satisfactory design is produced.

The aim of introducing the three types of reformulations is to expand the design state space so as to capture the *innovative and creative aspect of designing*.

Reformulation type I (**S** → **S'**), addresses changes in the design state space in terms of structure variables or ranges of values for them.

Reformulation type II (**S** → **Be'**), addresses changes in design state space in terms of behavior variables. A review of synthesized structure may lead to the addition of expected behavior variables.

Reformulation type III (**S** → **F'**), addresses changes in design state space in terms of function variables.

Kan, Gero & Sarkar 2010: Using a Generic Method to Study Software Design

FBS ontology of designing - processes

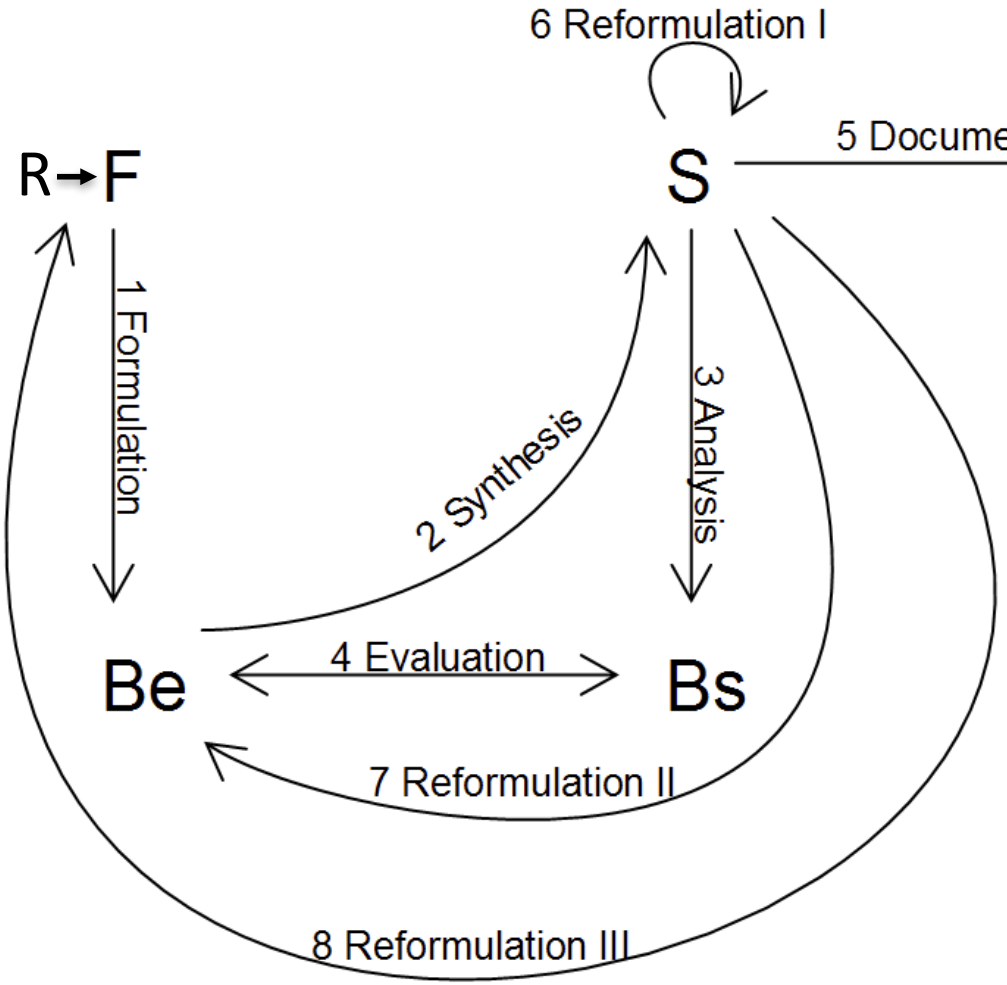
A design description is never transformed directly from the function but undergoes a series of **processes** among the FBS variables / issues

1 formulation
2 synthesis
3 analysis
4 evaluation
5 documentation
6-8 reformulation I, II, III
based on the structure

fundamental processes for designing

These eight processes are claimed to be the **fundamental processes for designing**.

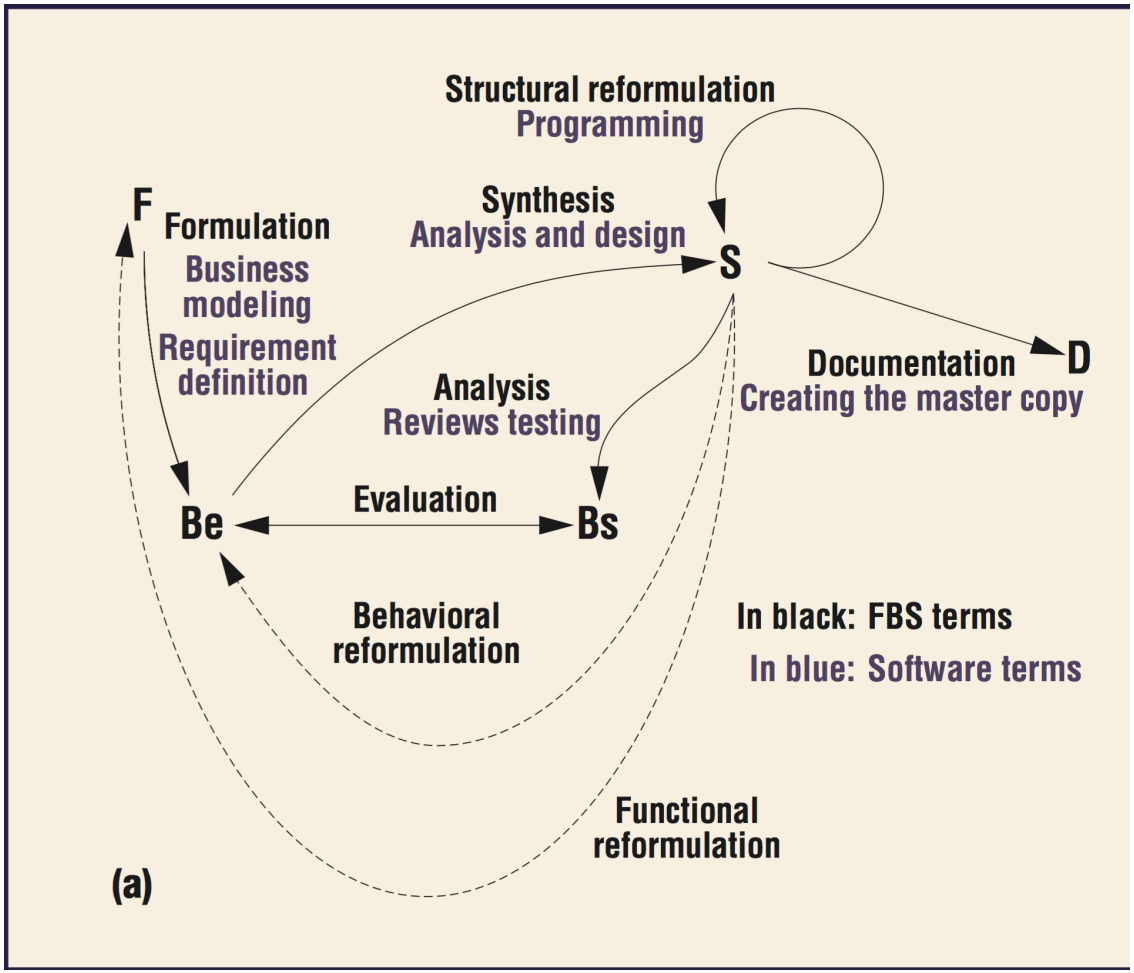
The FBS ontology of designing



Design Process	
Formulation (1)	R>F,F>Be
Synthesis (2)	Be>S
Analysis (3)	S>Bs
Documentation (5)	S>D
Evaluation (4)	Be<>Bs
Reformulation I (6)	S>S
Reformulation II (7)	S>Be
Reformulation II (8)	S>F

Kan & Gero: A Generic Tool to Study Human Design Activities. ICED'09/2 (p 239)

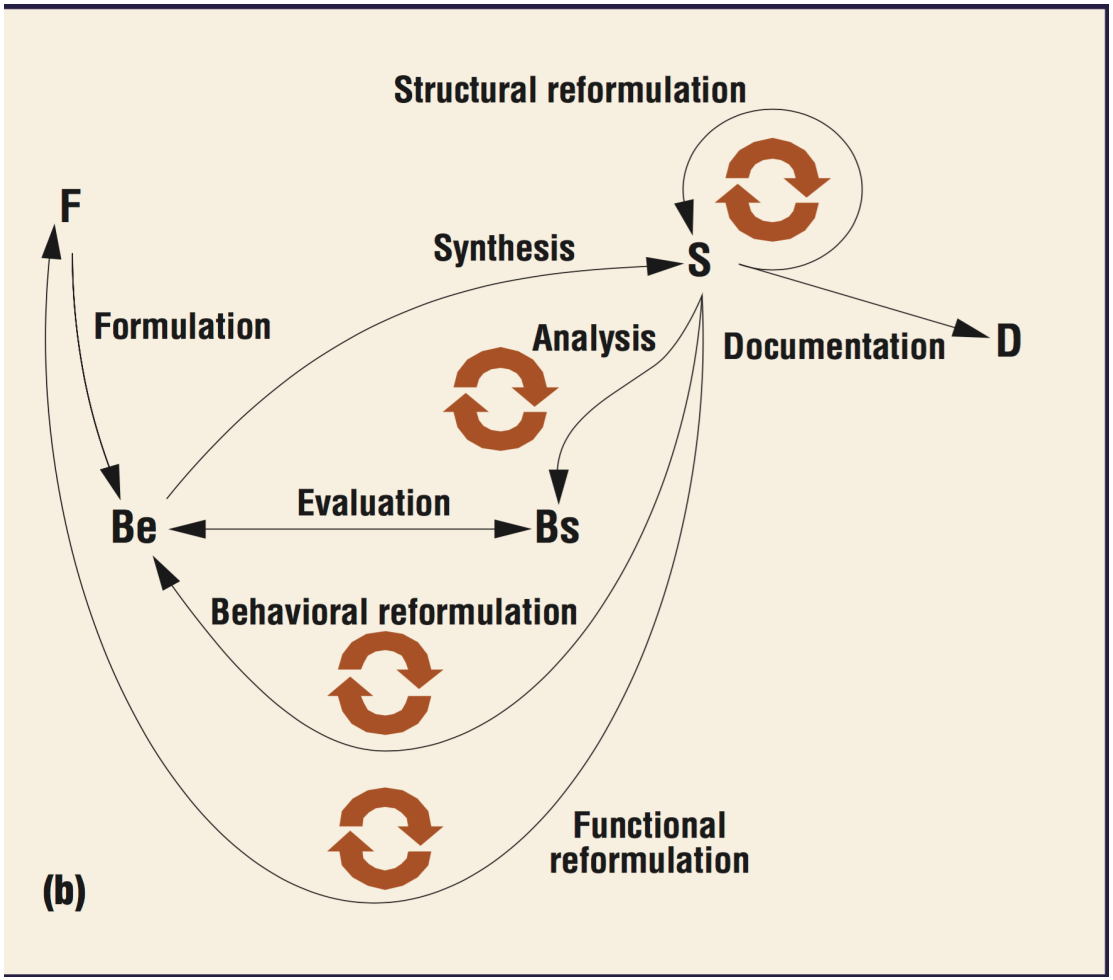
Software life cycles



(a) The **waterfall lifecycle model** (solid arrows) tries to go directly from F to D, with almost no loops or reformulations. Behavioral and functional reformations are strongly discouraged (dotted arrows).

(Kruchten P.: Casting Software Design in the Function-Behavior- Structure Framework. 2005 IEEE, p.56)

Software life cycles



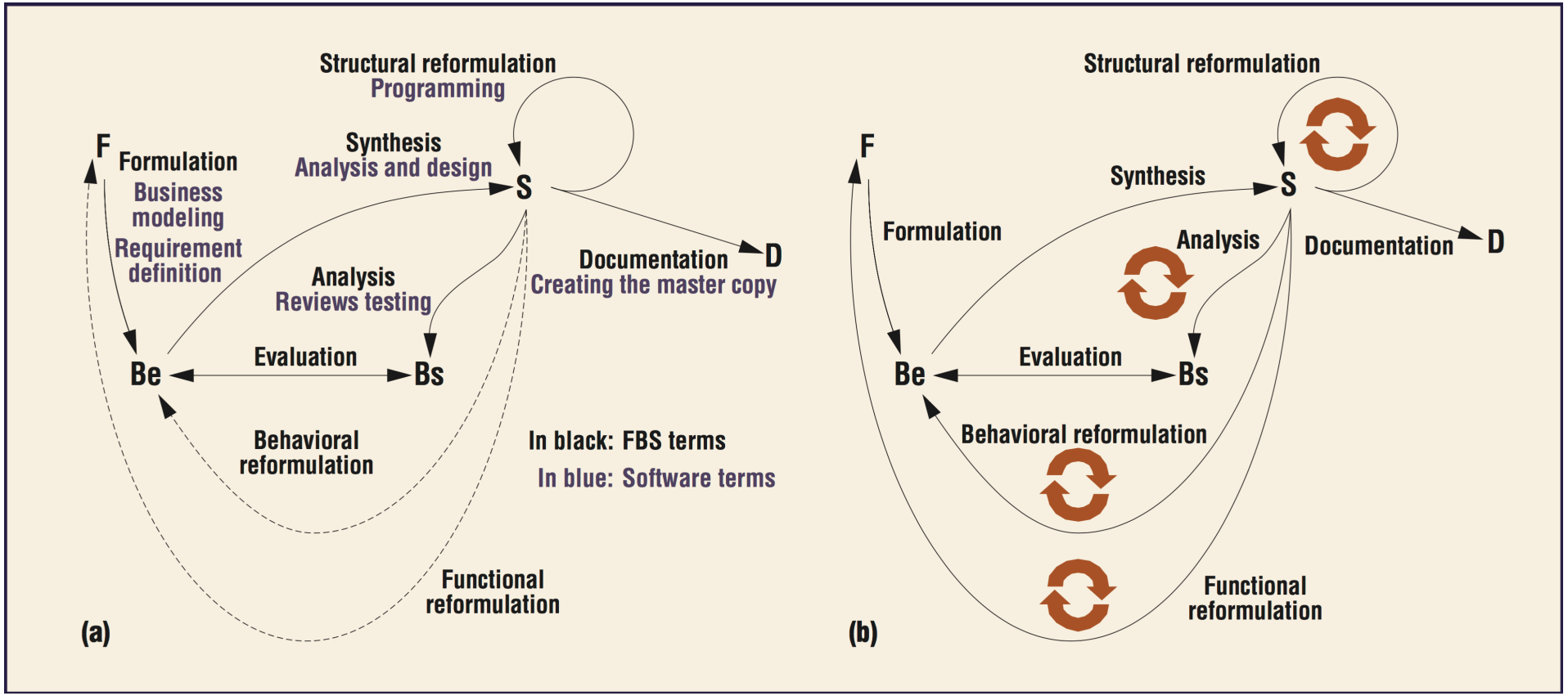
(b) **Iterative development** encourages many loops. Refactoring as the design emerges and encouraging customer involvement lead to constant reformulations (thick orange arrows).

(Kruchten P.: Casting Software Design in the Function-Behavior- Structure Framework. 2005 IEEE, p.56)

Software life cycles

(a) The waterfall lifecycle model (solid arrows)

(b) Iterative development



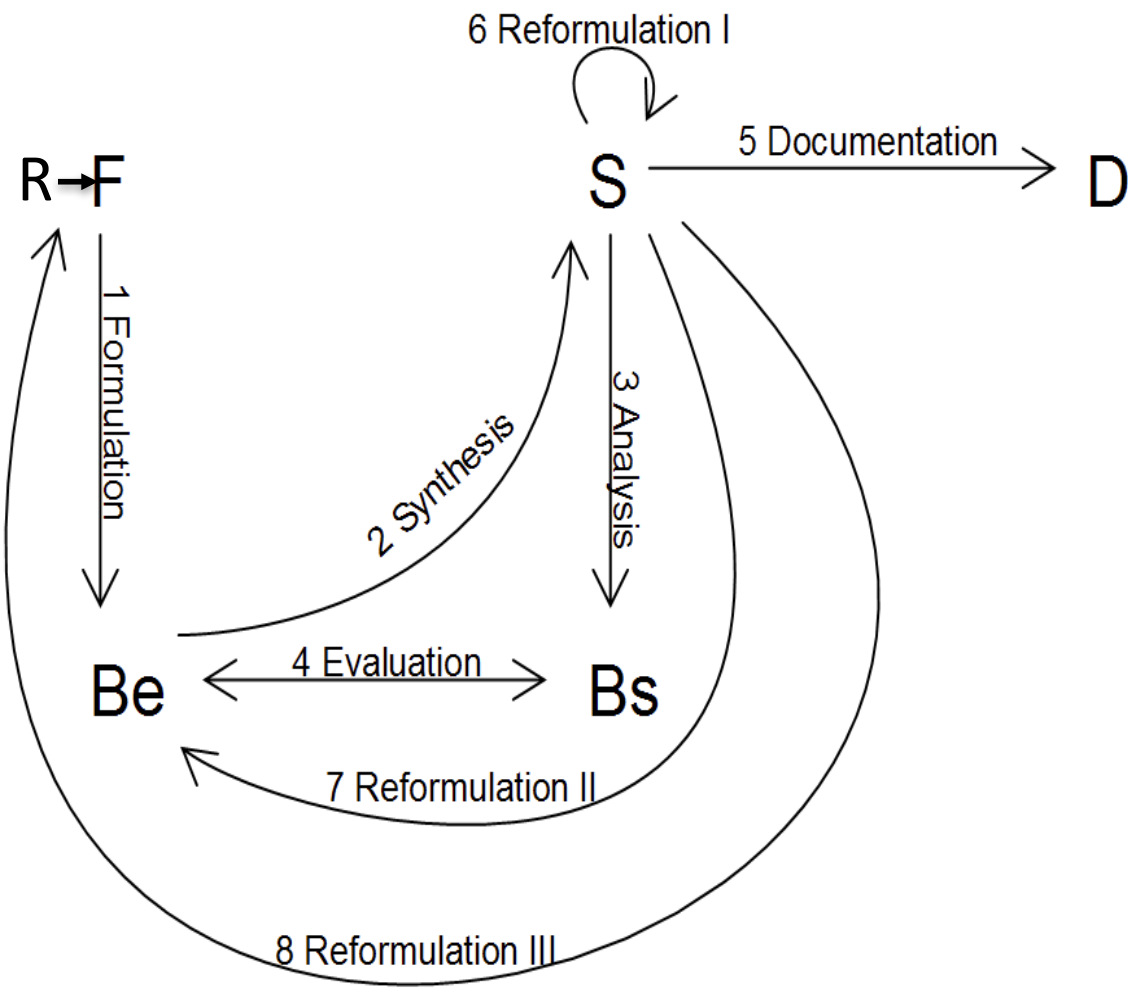
(Kruchten P.: Casting Software Design in the Function-Behavior- Structure Framework. 2005 IEEE, p.56)

Artifact mapping from FBS to RUP (Rational Unified Process)

FBS element	Definition	RUP artifacts
F	Set of functions	Vision document Stakeholders' needs Use case survey Business case
S	Synthesized structure	Design models Code
Be	Set of expected behaviors	Requirements Use case model Supplementary specification Use case storyboard, UI prototypes Test cases
Bs	Set of actual behaviors	Test results Inspection and review reports Measurements
D	Description	Executable code (installers, etc.) Other deployment artifacts (data, user guide, training material, etc.)

(Kruchten P.: Casting Software Design in the Function-Behavior- Structure Framework. 2005 IEEE, p.54)

The FBS ontology of designing



R … requirements
F … function
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⟶ … transformation
↔ … comparison

Code
R
F
Bs
Be
S
D

O
…other

Kan & Gero: A Generic Tool to Study Human Design Activities. ICED'09/2 (p 239)

Requirements (R)

- includes all expressions of (existing or fictitious) customer or market needs, demands, wishes and constraints that are explicitly provided to the designers at the outset of a design task.

e.g.: requirement issues include ‘technical performance requirements […] articulated by the customer’, ‘stakeholder requests, and ‘customer needs and wants’

Kannengiesser & Gero (2017) Can Pahl and Beitz' Systematic Approach be a predictive model of designing?

Function (F)

- purposes of the artefact being designed

  - any expression related to potential purposes of the artefact'

»what the artifact is for«

Unlike requirement issues, function issues are not directly provided to the designer; they are generated by the designer based on interpretations of requirement issues or design task.

Function issues in Systematic Approach include 'the intended input/output relationship of a system', examples of needs related to safety, aesthetics or economic properties.

Function issues include the notion of a use case.

Gero & Kannengiesser (2013) Commonalities across Designing

Expected Behaviour (Be)

- attributes that are expected from the artefact's structure (S);

  includes attributes that describe the artefact's expected interaction with the environment;

  »what the object does / (is expected to do)«

Expected Behaviour (Be) attributes can be used as guidance or assessment criteria for potential design solutions; attributes of an entity that allow comparison on a performance level.

Be issues in Systematic Approach e.g. "physical effects"; "technical, economic and safety criteria" for design evaluation

Gero & Kannengiesser (2013) Commonalities across Designing

Structure Behaviour (Bs)

- includes those attributes of the artefact that are measured, calculated or derived from observation of a specific design solution and its interaction with the environment.

»what the object does«

Instances of Structure Behaviour (Bs) must be of the same type as instances of Expected Behavior (Be), so as to allow comparing and evaluating design solutions.

Gero & Kannengiesser (2013) Commonalities across Designing

Structure (S)

- includes the components/elements of an artefact/design and their relationships.

»what the object consists of«

can appear either as a ‘concept structure’ or a ‘solution structure’, which are the outputs of phases 2 and 3 (im Vorgehensmodell VDI 2221);

includes ‘layout’ and ‘form’ (Pahl &Beitz, 2007, p. 227),

‘code’ (Kruchten, 2004, p. 256), and

‘detail designs’ (El-Haik and Roy, 2005, p. 7)

Description (D)

- includes any form of design-related representations produced by a designer, at any stage of the design process.

mechanical engineers may produce

– sketches, CAD models, requirements lists, physical prototypes, calculations, and other documentations

software designers produce Descriptions including

– storyboards, UML models, code files, test plans and other representations

Gero & Kannengiesser (2013) Commonalities across Designing

FBS coding

Code
R
F
Bs
Be
S
D

In **designing physical objects**, the manifestation of structure (S) variables will usually resemble some physical aspect.
Example: to design a portable shelter;
the **function (F)** of shelter can be formulated to **expected behaviors (Be)** of a space with simple erection method that provides protection.
This may be synthesized into an “A-frame” **structure (S)**.
With this structure, one can analysis its **behavior (Bs)**, for example headroom and structural stability.
After evaluating the behaviors, the designer may accept or reject this structure (S).

Mc Neill & Gero 1998: Understanding Conceptual Electronic Design

FBS coding

Code
R
F
Bs
Be
S
D

in the **design of software** the structure (S) will not have any physicality.

In a object-oriented program,

the objects are referred to as **structure (S)**.

The programmers (designers) formulate the **expected behaviors (Be)** from the functions of these objects.

With these expected behaviors they can synthesize the codes or the relationships of codes of those objects.

With these objects they can derive their behaviors **(Bs)** by either running that part of the program or mentally simulating their behaviors.

Mc Neill & Gero 1998: Understanding Conceptual Electronic Design…

FBS coding

Code
R
F
Bs
Be
S
D

It may be useful to think of the concepts of independent and dependent variables in a mathematical programming formalism to provide an analogy to the relationships between structure (S) and behaviors (Be and Bs).

An independent variable is one that may be varied freely or autonomously by a designer.

In a formula that computes area (area = length * breadth), length and breadth are examples of the independent variables.

A dependent variable is one that derives from the interaction that occurs between the independent variables, such that its behavior derives from the changes that are effected through the independent variables. Area, therefore, is a dependent behavior that derives from the individual changes that a designer makes to length or breadth.

In our coding protocol for the software design example, structure (S) comprises those variables that the designers indicate can be manipulated independently (or conceive that the users of the program may wish to do).

Mc Neill & Gero 1998: Understanding Conceptual Electronic Design

segmentation

cues for segmentation:

turn taking, pauses, intonation, contours

(Kan & Gero Using entropy to characterize design processes. in Artificial intelligence for engineering design analysis and manufacturing. 2017. p 4)

FBS Segmenting and Coding

The protocol/transcript is segmented and coded strictly based on these six categories of issues according to the rule:

one segment per code / one code per segment

The segmenting and coding are done simultaneously by discerning whether an action or utterance expresses the FBS aspect of designing or concerns the requirements or others.

If an utterance contains more than one class it will be further divided. This also applies to the 'O' (other) and 'R' codes.

Drawing and writing actions are also considered as segments of structure. (Kan & Gero, 2009: Using the FB Ontology …)

Coding procedure:

1. Each coder segments and codes the transcript separately.
2. The final coding is arbitrated based on coding of each coder. (inter-coder **reliability** is calculated)

Kan & Gero, 2009: Using the FB Ontology …

Reliability

of the FBS-based protocol coding

The agreement between coding of coders [%].

The agreement between the arbitrated and the first codings [%].

Coding1 vs Arbitrated (%)	Coding2 vs Arbitrated (%)
85.1	89.3

UE: FBS coding

(extract: engineering brainstorming session)

UE: FBS coding

(extract: engineering brainstorming session)

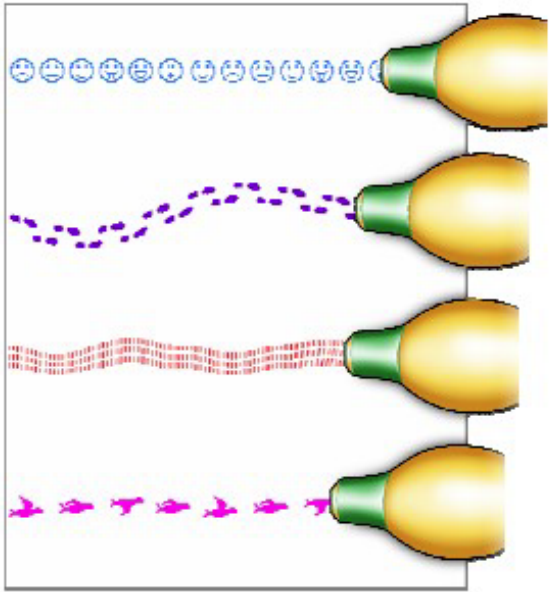
The design session concerned an innovative thermal printing pen as illustrated in Figure.

The aim of the engineering brainstorming session was to obtain ideas for a prototype of the pen. This involved solving problems such as keeping the print head in contact and at the optimum angle to the media, despite wobbly arm moment

7 cross-disciplinary participants were involved:

- 1 business consultant acted as the moderator;
- 3 mechanical engineers,
- 1 electronics business consultant,
- 1 ergonomicist, and
- 1 industrial design student

session lasted for 1 h 27 min



Brainstorm rules

Keep the creative juices flowing!

- All ideas, however ridiculous are valid; don't be afraid to use humour
- No criticism allowed of ideas or their proponents
- Any idea can be used as a springboard to another idea (combine, build, piggyback etc.)
- Do not interrupt
- If you can add detail to an idea, fine; if not don't worry
- Explain your ideas but do not ramble
- Think creatively - break some mind-sets
- Encourage/accept "childlike" behaviour (wishing, imagination etc.)
- Assume everything is possible - no constraints!!

Coding – example: thermal printing pen

The design session concerned an innovative thermal printing pen as illustrated in Figure.

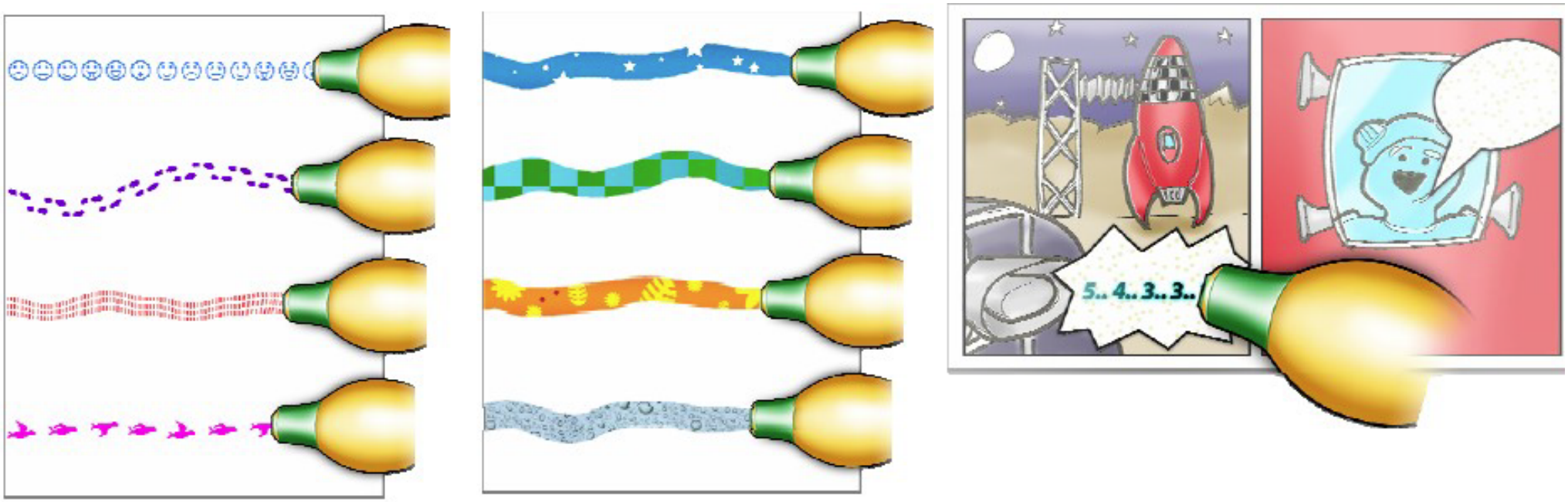


Figure: function and behavior of the design object: thermal printing pen.

UE: FBS coding

(extract: engineering brainstorming session)

	A	B	C	D	E	F	G	H	I	J
	JMBEI	UTTERANCE	CODE	LINKS						
1	1	J: I ended up with the (.) hold on (2.2) sledge	S							
2	2	A: the sledge excellent so what did that generate then? ((write: sledge))	D	1						
3	3	J: well the sledge manages to keep level by having quite a wide base	Bs	1						
4	4	A: ((write: wide base))	D	3						
5	5	J: and then a main force in the middle so	Bs	3	1					
6	6	J: unlike the set of skis	S	3	1					
7	7	J: where quite narrow and	S	6	3	1				
8	8	J:you go up on an edge- when you're turning	Bs	7	6	5	3	1		
9	9	J: the sledge is er quite broad	S	7	6	3	1			
10	10	J: and then you have the weight right in the middle	Bs	9	6	5	3	1		
11	11	J: so they manage to keep both runners on the snow-	Bs	10	9	8	5	3	1	
12	12	A: ((write: force in middle))	D	10	5					
13	13	J: more often than say a sledge or a snowboar- a skis or snowboard	Be	10	9	1				
14	14	A: some some guiders almost down the side of this	S	13	1					
15	15	J: well I guess the easiest way to keep the pen at a right angle would be	Be							
16	16	J: to have a set of stabilisers on it based on the idea of a sledge	S	15	9	3	1			
17	17	A: yeah no problem (.) stabilisers (6) like a bicycle yeah that's a good	S	16						
18	18	A: ((write: stabilizer))	D	16						

137 Jami I ended up with the (.) ((leaves through papers)) hold on (2.2) sledge

138 AJ the sledge [excellent

139 All [((laugh))

140 AJ so what did that generate then? ((writes: sledge))

141 Jami well the sledge manages to keep level by having quite a wide base ((gestures)) an

142 then a main force in the middle (.) so unlike the set of skis where quite

143 narrow and you go up on an edge-

144 AJ yeah

145 Jami when you're turning

146 AJ yeah

147 Jami the sledge is er quite broad and then you have the weight right in

148 the middle so they manage to keep both runners on the snow-

149 AJ yeah ((writes: force in the middle))

150 Jami more often than say a sledge or a snowboar- a skis or snowboard

151 AJ ((hand gesture)) so so would you potential see some some some guiders almost down

152 the side of this?

153 Jami well I guess the easiest way to keep the pen at a right angle would be

154 to have a set of stabilisers on it

155 AJ yeah

156 Jami based on the idea of a sledge

157 AJ yeah no problem stabilisers (6) ((writes: stabiliser)) like a bicycle

FBS coding segments

NR.	UTTERANCE	CODE	LINKS
1	J: I ended up with the (.) hold on (2.2) sledge		
2	A: the sledge excellent so what did that generate then? ((write: sledge))		
3	J: well the sledge manages to keep level by having quite a wide base		
4	A: ((write: wide base))		
5	J: and then a main force in the middle so		
6	J: unlike the set of skis		
7	J: where quite narrow and		
8	J: you go up on an edge- when you're turning		
9	J: the sledge is er quite broad		
10	J: and then you have the weight right in the middle		
11	J: so they manage to keep both runners on the snow-		
12	A: ((write: force in middle))		
13	J: more often than say a sledge or a snowboar- a skis or snowboard		
14	A: some some guiders almost down the side of this		
15	J: well I guess the easiest way to keep the pen at a right angle would be		
16	J: to have a set of stabilisers on it based on the idea of a sledge		
17	A: yeah no problem (.) stabilisers (6) like a bicycle yeah that's a good		
18	A: ((write: stabilizer))		

FBS coded segments

(extract: engineering brainstorming session)

NUMBER	UTTERANCE	CODE	LINKS
38	I ended up with the+ hold on+ sledge	S	
39	the sledge excellent so what did that generate then? ((write: sledge))	D	
40	well the sledge manages to keep level by having quite a wide base	Bs	
41	((write: wide base))	D	
42	and then a main force in the middle so	Bs	
43	unlike the set of skis	S	
44	where quite narrow and	S	
45	you go up on an edge- when you're turning	Bs	
46	the sledge is er quite broad	S	
47	and then you have the weight right in the middle	Bs	
48	so they manage to keep both runners on the snow-	Bs	
49	((write: force in middle))	D	
50	more often than say a sledge or a snowboar- a skis or snowboard	Be	
51	some some guiders almost down the side of this	S	
52	well I guess the easiest way to keep the pen at a right angle would be	Be	
53	to have a set of stabilisers on it based on the idea of a sledge	S	
54	yeah no problem++ stabilisers +++like a bicycle yeah that's a good	S	
55	A: ((write: stabilizer))	D	

FBS coded segments

(extract: engineering brainstorming session)

comments

“J suggested an object (structure) – “sledge” (segment 38) – and continued to explain the behaviour of the sledge: how it maintains contact or level on the snow (segment 40 and 48).

The sledge was compared with a set of skis (segment 43) in terms of the structure (segment 44) and behaviour (segments 45, 47 and 48).

The coding of segment 50 can be controversial;

it was coded as expected behaviour (Be) as we interpreted J was borrowing the behaviour of the analogised objects and targeting those to be the

expected behaviour of the designed object.

Finally, the structure of stabilisers (segment 53) was suggested.“

(Kan & Gero, 2009: Using the FB Ontology …)

FBS coded segments (extract: engineering brainstorming session)

NUMBE	UTTERANCE	CODE
1	J: I ended up with the (.) hold on (2.2) sledge	S
2	A: the sledge excellent so what did that generate then? ((write: sledge))	D
3	J: well the sledge manages to keep level by having quite a wide base	Bs
4	A: ((write: wide base))	D
5	J: and then a main force in the middle so	Bs
6	J: unlike the set of skis	S
7	J: where quite narrow and	S
8	J: you go up on an edge- when you're turning	Bs
9	J: the sledge is er quite broad	S
10	J: and then you have the weight right in the middle	Bs
11	J: so they manage to keep both runners on the snow-	Bs
12	A: ((write: force in middle))	D
13	J: more often than say a sledge or a snowboar- a skis or snowboard	Be
14	A: some some guiders almost down the side of this	S
15	J: well I guess the easiest way to keep the pen at a right angle would be	Be
16	J: to have a set of stabilisers on it based on the idea of a sledge	S
17	A: yeah no problem (.) stabilisers (6) like a bicycle yeah that's a good	S
18	A: ((writes: stabiliser))	D

“J suggested an object (structure) – “sledge” (segment 1) – and continued to explain the behaviour of the sledge: how it maintains contact or level on the snow (segment 3 and 11).
The sledge was compared with a set of skis (segment 6) in terms of the structure (segment 7) and behaviour (segments 8, 10 and 11) .“ (Kan & Gero, 2009)

FBS coded segments (extract: engineering brainstorming session)

NUMBE	UTTERANCE	CODE
1	J: I ended up with the (.) hold on (2.2) sledge	S
2	A: the sledge excellent so what did that generate then? ((write: sledge))	D
3	J: well the sledge manages to keep level by having quite a wide base	Bs
4	A: ((write: wide base))	D
5	J: and then a main force in the middle so	Bs
6	J: unlike the set of skis	S
7	J: where quite narrow and	S
8	J:you go up on an edge- when you're turning	Bs
9	J: the sledge is er quite broad	S
10	J: and then you have the weight right in the middle	Bs
11	J: so they manage to keep both runners on the snow-	Bs
12	A: ((write: force in middle))	D
13	J: more often than say a sledge or a snowboar- a skis or snowboard	Be
14	A: some some guiders almost down the side of this	S
15	J: well I guess the easiest way to keep the pen at a right angle would be	Be
16	J: to have a set of stabilisers on it based on the idea of a sledge	S
17	A: yeah no problem (.) stabilisers (6) like a bicycle yeah that's a good	S
18	A: ((write: stabilizer))	D

“The coding of segment 13 can be controversial; it was coded as expected behaviour (Be) as we interpreted J was borrowing the behaviour of the analogised objects and targeting those to be the expected behaviour of the designed object. Finally, the structure of stabilisers (segment 16) was suggested.“ (Kan & Gero, 2009)

FBS coded segments (extract: engineering brainstorming session)

NUMBE	UTTERANCE	CODE
1	J: I ended up with the (.) hold on (2.2) sledge	S
2	A: the sledge excellent so what did that generate then? ((write: sledge))	D
3	J: well the sledge manages to keep level by having quite a wide base	Bs
4	A: ((write: wide base))	D
5	J: and then a main force in the middle so	Bs
6	J: unlike the set of skis	S
7	J: where quite narrow and	S
8	J:you go up on an edge- when you're turning	Bs
9	J: the sledge is er quite broad	S
10	J: and then you have the weight right in the middle	Bs
11	J: so they manage to keep both runners on the snow-	Bs
12	A: ((write: force in middle))	D
13	J: more often than say a sledge or a snowboar- a skis or snowboard	Be
14	A: some some guiders almost down the side of this	S
15	J: well I guess the easiest way to keep the pen at a right angle would be	Be
16	J: to have a set of stabilisers on it based on the idea of a sledge	S
17	A: yeah no problem (.) stabilisers (6) like a bicycle yeah that's a good	S
18	A: ((write: stabilizer))	D

linking segments

(extract: engineering brainstorming session)

NR.	UTTERANCE	CODE	LINKS					
1	I ended up with the+ hold on+ sledge	S						
2	the sledge excellent so what did that generate then? ((write: sledge))	D						
3	well the sledge manages to keep level by having quite a wide base	Bs						
4	((write: wide base))	D						
5	and then a main force in the middle so	Bs						
6	unlike the set of skis	S						
7	where quite narrow and	S						
8	you go up on an edge- when you're turning	Bs						
9	the sledge is er quite broad	S						
10	and then you have the weight right in the middle	Bs						
11	so they manage to keep both runners on the snow-	Bs						
12	((write: force in middle))	D						
13	more often than say a sledge or a snowboar- a skis or snowboard	Be						
14	some some guiders almost down the side of this	S						
15	well I guess the easiest way to keep the pen at a right angle would be	Be						
16	to have a set of stabilisers on it based on the idea of a sledge	S						
17	yeah no problem++ stabilisers +++like a bicycle yeah that's a good	S						
18	A: ((write: stabilizer))	D						

coding examples

Example of **requirements R**:

"quite important is its about the thermal-incli- inclis ( ) pen" (E1, 43)

"design a-a prototype" (E1, 56-57)

Examples of **function F**:

"that's the standard plain thermal paper err and then it can draw" (E1, 54)

Examples of **expected behaviour Be**:

"either atoms or line types" (E1, 55)

"we can print thermo reactive dyes onto media substrates" (E1, 68)

Examples of **derived behaviour Bs**:

"it'll be about fifty percent more expensive" (E1, 199)

"if you lift an optical mouse slightly off the page you'll see the pattern it creates" (E1, 672 674)

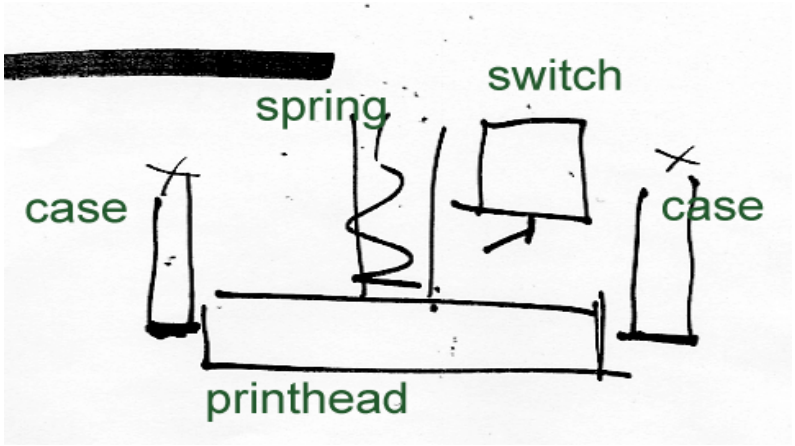
coding examples

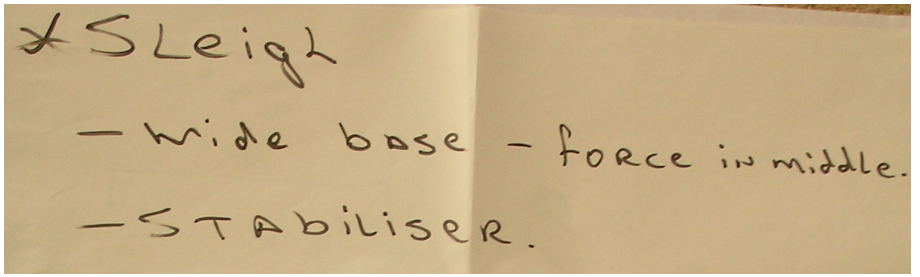
Examples of **structure S**:

"…sledge" (E1, 137)

"show the relative size of the pen if you've got an example" (E1, 171)

Example of design **description D**:





Examples of **others O**:

"yeah we'll come to that in a minute" (E1, 737)

jokes or communications that are not related to the design process or the resulting artefact.

Kan & Gero, 2009: Using the FB Ontology …

Linkography

Linkography was introduced to protocol analysis by Goldschmidt.

The design protocol is decomposed into small units - most basic operations -"**design moves**" (≈ segments) = "a step, an act, an operation, which transforms the design situation relative to the state in which it was prior to that move".

"I define a design move as an act of reasoning that presents a coherent proposition pertaining to an entity that is being designed." (Goldschmidt, 1992, p72)

A linkograph is constructed by linking related moves.

Kan, Gero & Tang, 2010: Measuring Cognitive Design Activity Changes During an Industry Team Brainstorming Session. *Design Computing and Cognition* DCC'10

Linkography

A linkograph is constructed by breaking design protocols into ‘segments’ (or ‘moves’) and then connecting them - independent of the code -

by a coder using domain knowledge and commonsense.

Sequential ‘moves’ are placed along the horizontal axis. When two ‘moves’ are related, they are joined by a “link.”

Linkography is a technique used in analyzing design protocols.

to reveal the quality of a design process (Goldschmidt, 1992 , 1995) and the creativity of ideas (van der Lugt, 2003; Goldschmidt et.al, 2005)

(Kan & Gero: Using entropy to characterize design processes. in Artificial intelligence for engineering design analysis and manufacturing. 2017. p 4)

linkography

linkability of segments

Each move / segment is inspected by a human expert investigator to determine whether or not it maintains a **logical link to one or more antecedent moves** / **segments**

(a semantic relationships of the codes)

in the chronological sequence of design moves (issues, codes) as recorded in the protocol.

Goldschmidt 1992: Criteria For Design Evaluation: A Process-oriented Paradigm, p72

Data input for LINKODER
coded segments, links (excel spreadsheet)

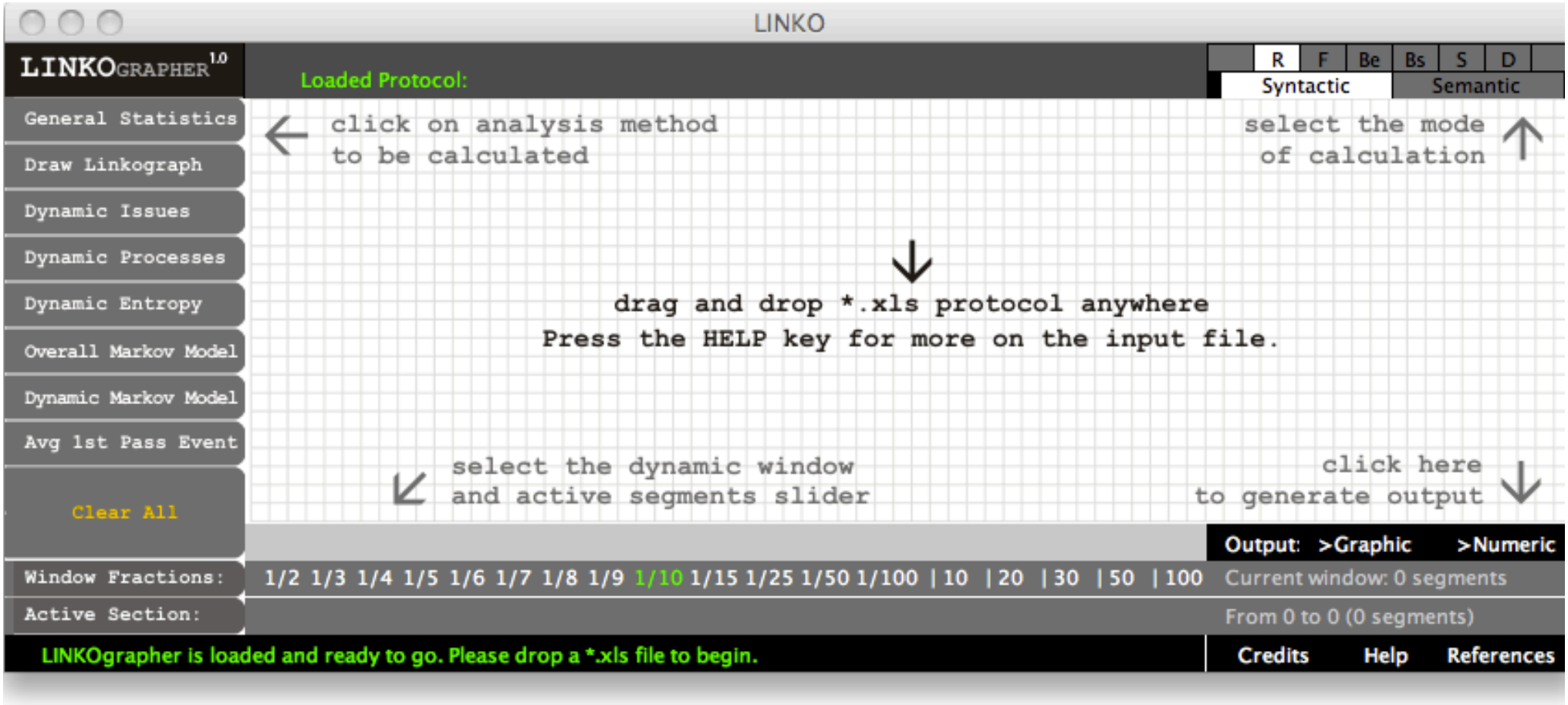
	A	B	C	D	E	F	G	H	I	J
1	NUMBE	UTTERANCE	CODE	LINKS						
2	38	J: I ended up with the+ hold on+ sledge	S							
3	39	A: the sledge excellent so what did that generate then? ((write: sledge))	D	38						
4	40	J: well the sledge manages to keep level by having quite a wide base	Bs	38						
5	41	A: ((write: wide base))	D	40						
6	42	J: and then a main force in the middle so	Bs	40	38					
7	43	J: unlike the set of skis	S	40	38					
8	44	J: where quite narrow and	S	43	40	38				
9	45	J: you go up on an edge- when you're turning	Bs	44	43	42	40	38		
10	46	J: the sledge is er quite broad	S	44	43	40	38			
11	47	J: and then you have the weight right in the middle	Bs	46	43	42	40	38		
12	48	J: so they manage to keep both runners on the snow-	Bs	47	46	45	42	40	38	
13	49	A: ((write: force in middle))	D	47	42					
14	50	J: more often than say a sledge or a snowboar- a skis or snowboard	Be	47	46	38				
15	51	A: some some guiders almost down the side of this	S	50	38					
16	52	J: well I guess the easiest way to keep the pen at a right angle would be	Be							
17	53	J: to have a set of stabilisers on it based on the idea of a sledge	S	52	46	40	38			
18	54	A: yeah no problem++ stabilisers +++like a bicycle yeah that's a good	S	53						
19	55	A: ((write: stabilizer))	D	53						
20										

http://www.linkoder.com/

accessed: 02.05.2018

LINKODER

http://www.linkoder.com/



LINKODER

	A	B	C	D	E	F	G	H	I	J
1	NUMBE	UTTERANCE	CODE	LINKS						
2	38	J: I ended up with the+ hold on+ sledge	S							
3	39	A: the sledge excellent so what did that generate then? ((write: sledge))	D	38						
4	40	J: well the sledge manages to keep level by having quite a wide base	Bs	38						
5	41	A: ((write: wide base))	D	40						
6	42	J: and then a main force in the middle so	Bs	40	38					
7	43	J: unlike the set of skis	S	40	38					
8	44	J: where quite narrow and	S	43	40	38				
9	45	J: you go up on an edge- when you're turning	Bs	44	43	42	40	38		
10	46	J: the sledge is er quite broad	S	44	43	40	38			
11	47	J: and then you have the weight right in the middle	Bs	46	43	42	40	38		
12	48	J: so they manage to keep both runners on the snow-	Bs	47	46	45	42	40	38	
13	49	A: ((write: force in middle))	D	47	42					

LINKODER

Revision 13/07/2011

Loaded Protocol: DTRSextract1_coded.xls

Statistics

General Statistics
Draw Linkograph
Dynamic Issues
Dynamic Processes
Dynamic Entropy
Overall Markov Model
Dynamic Markov Model
Avg 1st Pass Event
Clear All

Total Segments: 18
Non-FBS Segments: 0 (% 0)
Total Links: 43 (2,39 per seg)
Issue Activity (X)
Mean 7,7 STD 3,6
Link Distance (Y)
Mean 4,7 STD 3,7

Issue Distribution (%)	
R	0 (0,0)
F	0 (0,0)
Be	2 (11,1)
Bs	5 (27,8)
S	7 (38,9)
D	4 (22,2)

Process Distribution	Syntactic (%)	Semantic (%)
Formulation	0 (0,0)	0 (0,0)
Synthesis	2 (22,2)	2 (13,3)
Analysis	2 (22,2)	5 (33,3)
Evaluation	0 (0,0)	1 (6,7)
Documentation	2 (22,2)	1 (6,7)
Reformulation I	2 (22,2)	5 (33,3)
Reformulation II	1 (11,1)	1 (6,7)
Reformulation III	0 (0,0)	0 (0,0)

	Forelinks	Backlinks	Horizonlinks
Entropy:	8,392	12,326	10,612

General statistics from segment 1 to 18.

Output: >Graphic >Numeric

Window Fractions: 1/2 1/3 1/4 1/5 1/6 1/7 1/8 1/9 1/10 1/15 1/25 1/50 1/100 | 10 | 20 | 30 | 50 | 100 Current window 2 segments

Active Section: From 1 to 18 (18 segments)

LINKODER

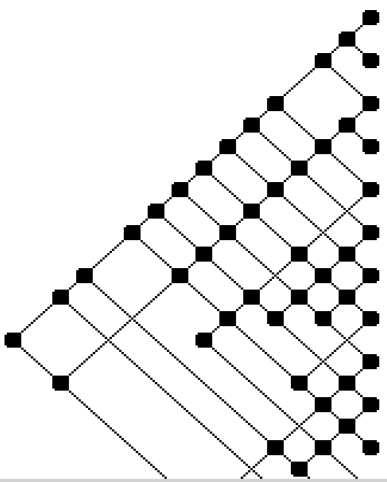
	A	B	C	D	E	F	G	H	I	J
1	NUMBE	UTTERANCE	CODE	LINKS						
2	38	J: I ended up with the+ hold on+ sledge	S							
3	39	A: the sledge excellent so what did that generate then? ((write: sledge))	D	38						
4	40	J: well the sledge manages to keep level by having quite a wide base	Bs	38						
5	41	A: ((write: wide base))	D	40						
6	42	J: and then a main force in the middle so	Bs	40	38					
7	43	J: unlike the set of skis	S	40	38					
8	44	J: where quite narrow and	S	43	40	38				
9	45	J: you go up on an edge- when you're turning	Bs	44	43	42	40	38		
10	46	J: the sledge is er quite broad	S	44	43	40	38			
11	47	J: and then you have the weight right in the middle	Bs	46	43	42	40	38		
12	48	J: so they manage to keep both runners on the snow-	Bs	47	46	45	42	40	38	
13	49	A: ((write: force in middle))	D	47	42					

LINKODER

LINKODER 1.1

Loaded Protocol: DTRSextract1_coded.xls

General Statistics
Draw Linkograph
Dynamic Issues
Dynamic Processes
Dynamic Entropy
Overall Markov Model
Dynamic Markov Model
Avg 1st Pass Event
Clear All



1 S J: I ended up with the (.) hold on (2.2) sledge
2 D A: the sledge excellent so what did that generate
3 Bs J: well the sledge manages to keep level by having
4 D A: ((write: wide base))
5 Bs J: and then a main force in the middle so
6 S J: unlike the set of skis
7 S J: where quite narrow and
8 Bs J:you go up on an edge- when you're turning
9 S J: the sledge is er quite broad
10 Bs J: and then you have the weight right in the middl
11 Bs J: so they manage to keep both runners on the sr

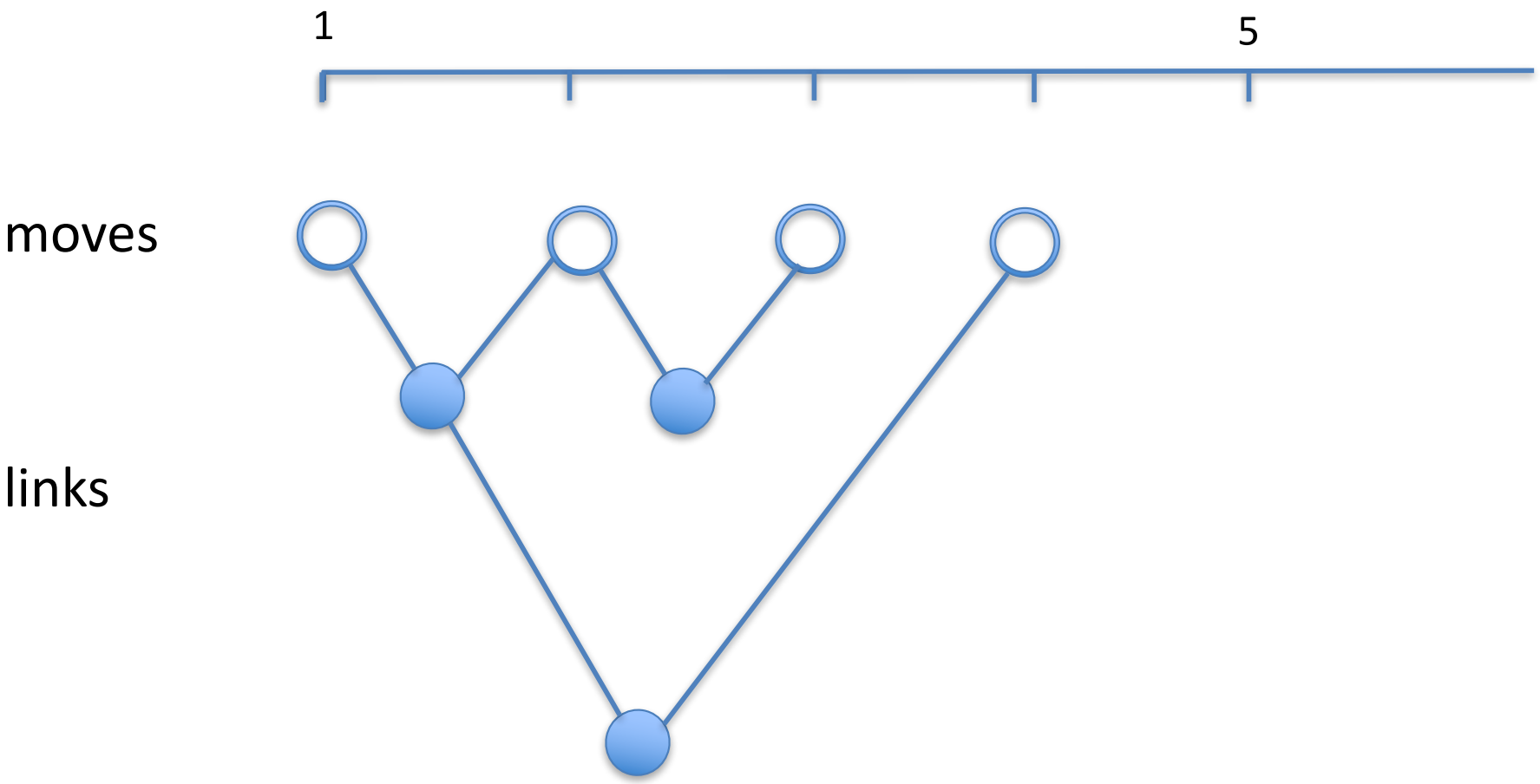
Move mouse horizontally to scroll the linkograph preview.

Output: >Graphic >Numeric

Window Fractions: 1/2 1/3 1/4 1/5 1/6 1/7 1/8 1/9 1/10 1/15 1/25 1/50 1/100 | 10 | 20 | 30 | 50 | 100 Current window 2 segments

Active Section: From 1 to 18 (18 segments)

linkograph



Goldschmidt 1992: Criteria For Design Evaluation: A Process-oriented Paradigm, p74

Producing Design Processes from a Linkograph

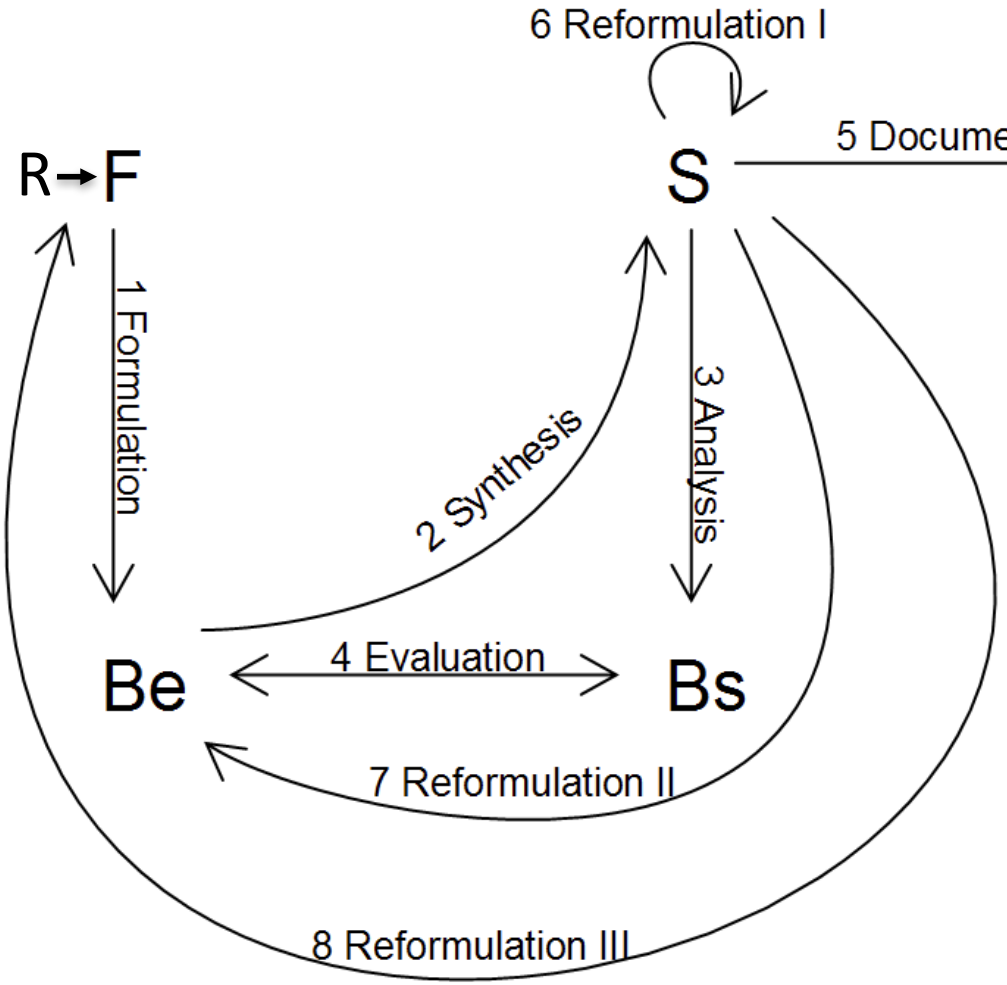
(some) **links** are viewed as **design processes**.

The linkograph become a network of (semantic) transformation processes.

There are 6 categories of FBS codes, excluding O, so there will be 36 types of possible transformations.

However, according to the FBS ontology many of those processes have no meaning. For example no instance of R>D was recorded. However there was a record of the F>S process which the framework does not permit.

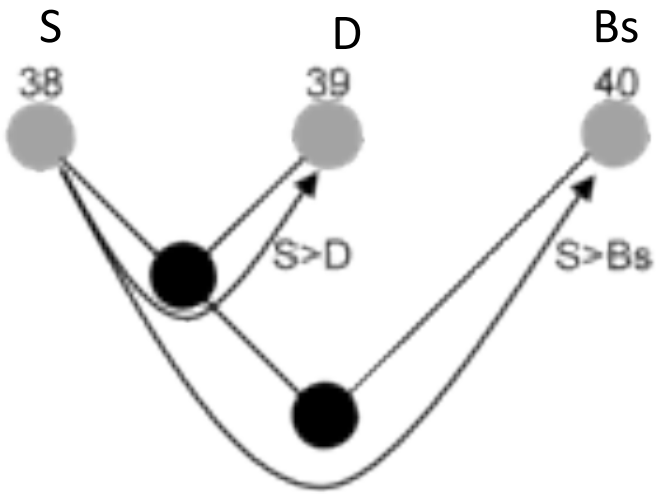
The FBS ontology of designing



Design Process	
Formulation (1)	R>F,F>Be
Synthesis (2)	Be>S
Analysis (3)	S>Bs
Documentation (5)	S>D
Evaluation (4)	Be<>Bs
Reformulation I (6)	S>S
Reformulation II (7)	S>Be
Reformulation II (8)	S>F

Kan & Gero: A Generic Tool to Study Human Design Activities. ICED'09/2 (p 239)

deriving design processes from linkograph



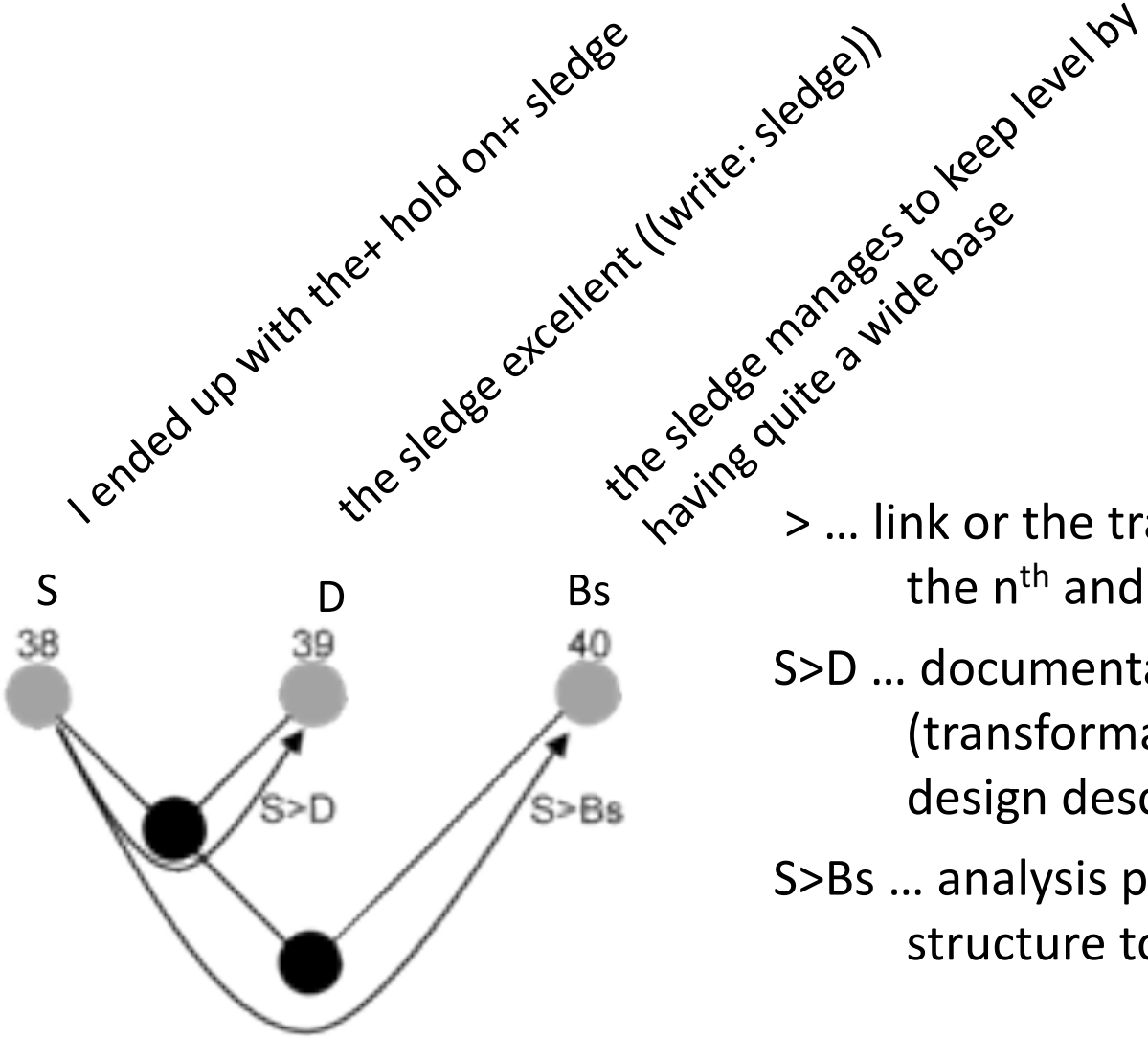
> … link or the transformation between the n^{th} and the $(n+i)^{th}$ segments

S>D … documentation process (transformation from structure to design description)

S>Bs … analysis process (transformation structure to behaviour)

Kan & Gero, 2009: Using the FB Ontology to Capture…

deriving transformation processes from linkograph



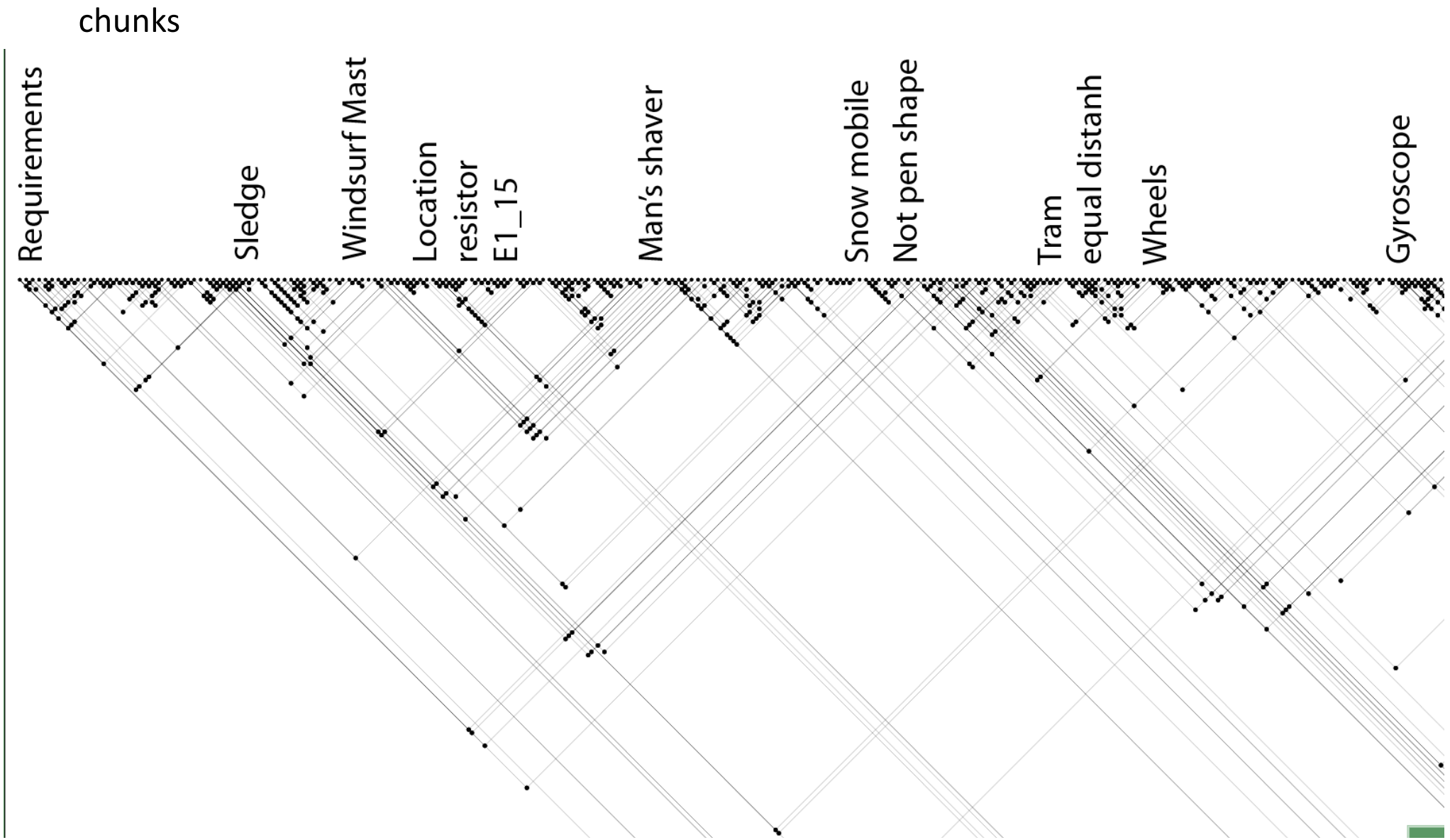
> … link or the transformation between the n^{th} and the $(n+i)^{th}$ segments

S>D … documentation process (transformation from structure to design description)

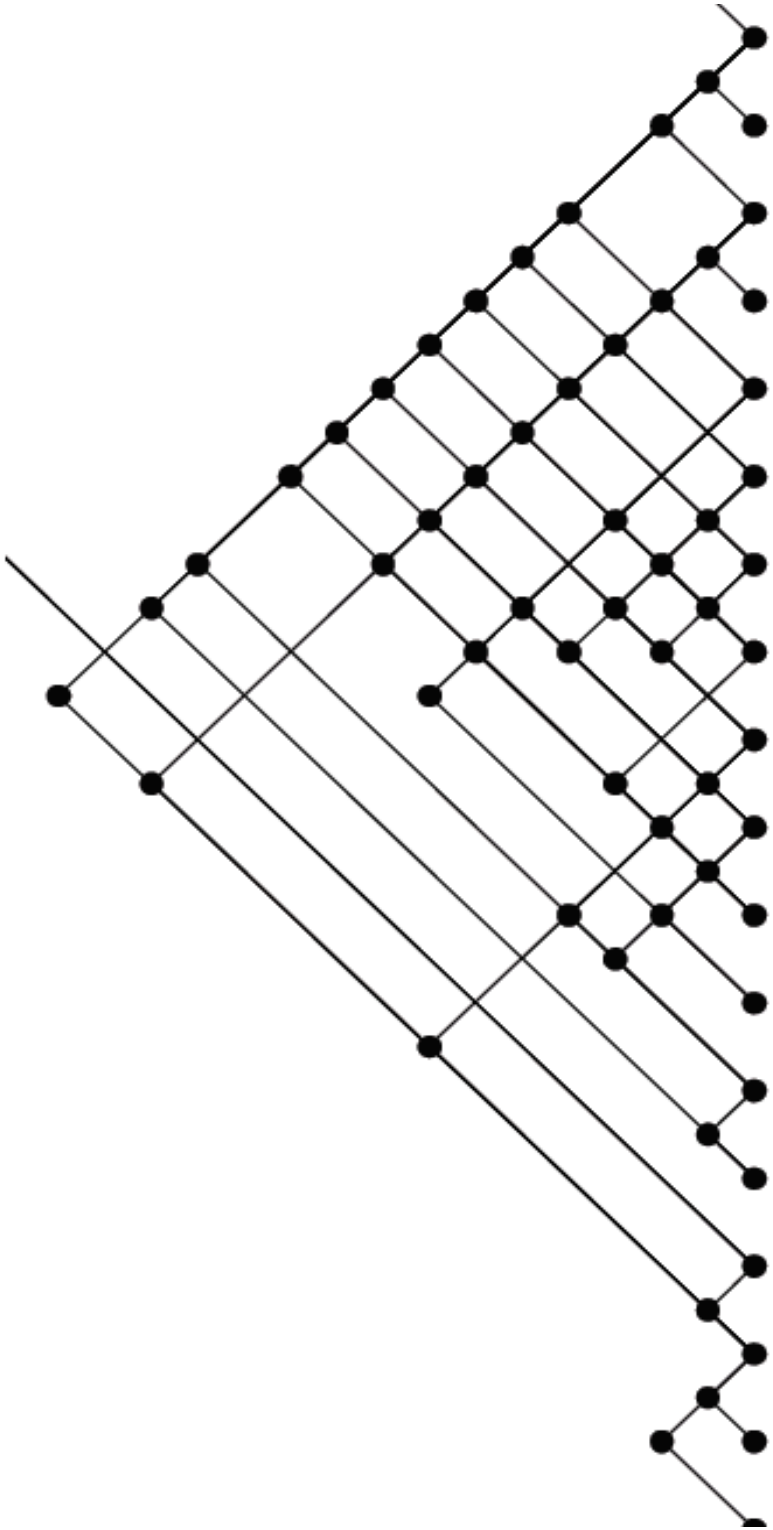
S>Bs … analysis process (transformation structure to behaviour)

Kan & Gero, 2009: Using the FB Ontology to Capture…

Part of the linkograph of the segmented protocol



Kan & Gero 2009: Using the FBS Ontology to Capture Semantic Design Information in Design Protocol Studies



38	S	J: I ended up with the + hold on +sledge
39	D	A: the sledge excellent so what did that generate then? (write: sledge)
40	Bs	J: the sledge manages to keep level by having quite a wide base
41	D	A: (write: wide base)
42	Bs	J: a main force in the middle
43	S	J: unlike the set of skis
44	S	J: where quite narrow and
45	Bs	J: you go up on an edge when you're turning
46	S	J: the sledge is er quite broad
47	Bs	J: and then you have the weight right in the middle
48	Bs	so they manage to keep both runners on the snow
49	D	A: (write: force in middle)
50	Be	J: a sledge or a snowboar- a skis or snowboard
51	S	A: some guiders almost down the side of this
52	Be	J: the easiest way to keep the pen at a right angle would be
53	S	J: to have a set of stabilisers on it based on the idea of a sledge
54	S	A: stabilisers +++like a bicycle yeah that's a good