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Automated Concept Generation Based On Function-Form Synthesis

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PRESENTATION OVERVIEW

Research Motivation

- Challenges for generating design concepts

Related Research

- Engineering design methodologies relating to concept generation

Methodology

- Creating a database of products
- Identifying candidate source products with functional similarities
- Creating tangible design concepts
  - Combine source product forms
  - Combine source product functions

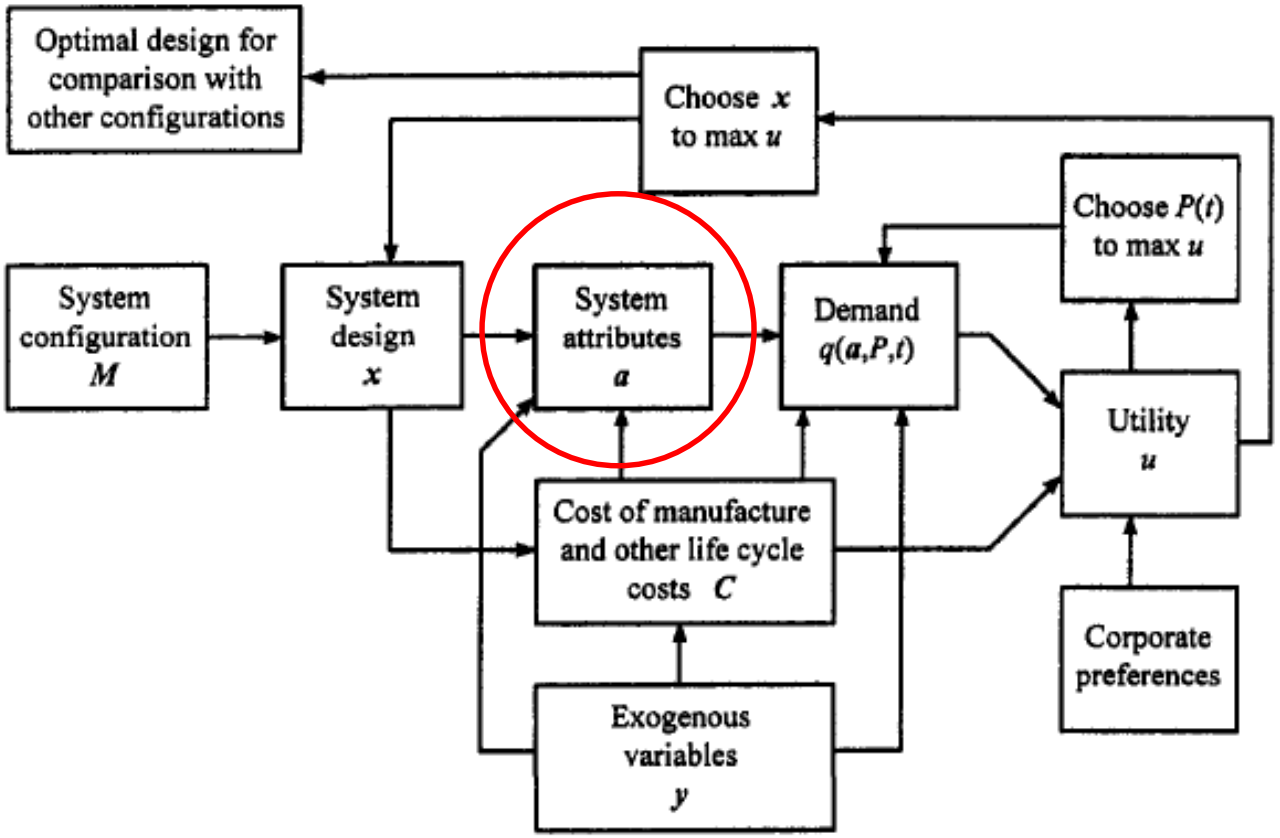
Application

- Generating a design concept for a hybrid marine model

Conclusion

Research motivation

Design factors in product design



A Framework for Decision based Engineering Design, G.A.Hazelrigg,1998

Demand = f(product , price , time)

"Optimize Price while Maximizing Utility"

Design factors in product design

- **Lower product differentiation → results in lower competitive edge**

	a1	a2	a3	a4	…
Company 1	✓	✓	✓	✓	…
Company 2	✓	✓	✓	✓	…
…	✓	✓	✓	✓	…

Shaked and Sutton, 1982

- **Higher product differentiation → may increase a company's competitive edge**

	a1	a2	a3	a4	ai	aj	ak
Company 1	✓	✓	✓	✓			
Company 2			✓	✓	✓	✓	✓

Shooter and Simpson, 2006

Company 1

Company 2

Research Questions

How can designers explore potentially relevant attributes from large scale data in timely efficient manner?

Research hypothesis

	Product attributes		
Next generation product (R)	R_i	R_j	R_k
Synthesized design concept (C)	C_i	C_j	C_k
Existing product (S)	S_i	S_j	S_k

$\Delta(X) = R - C$

$\Delta(Y) = R - S$

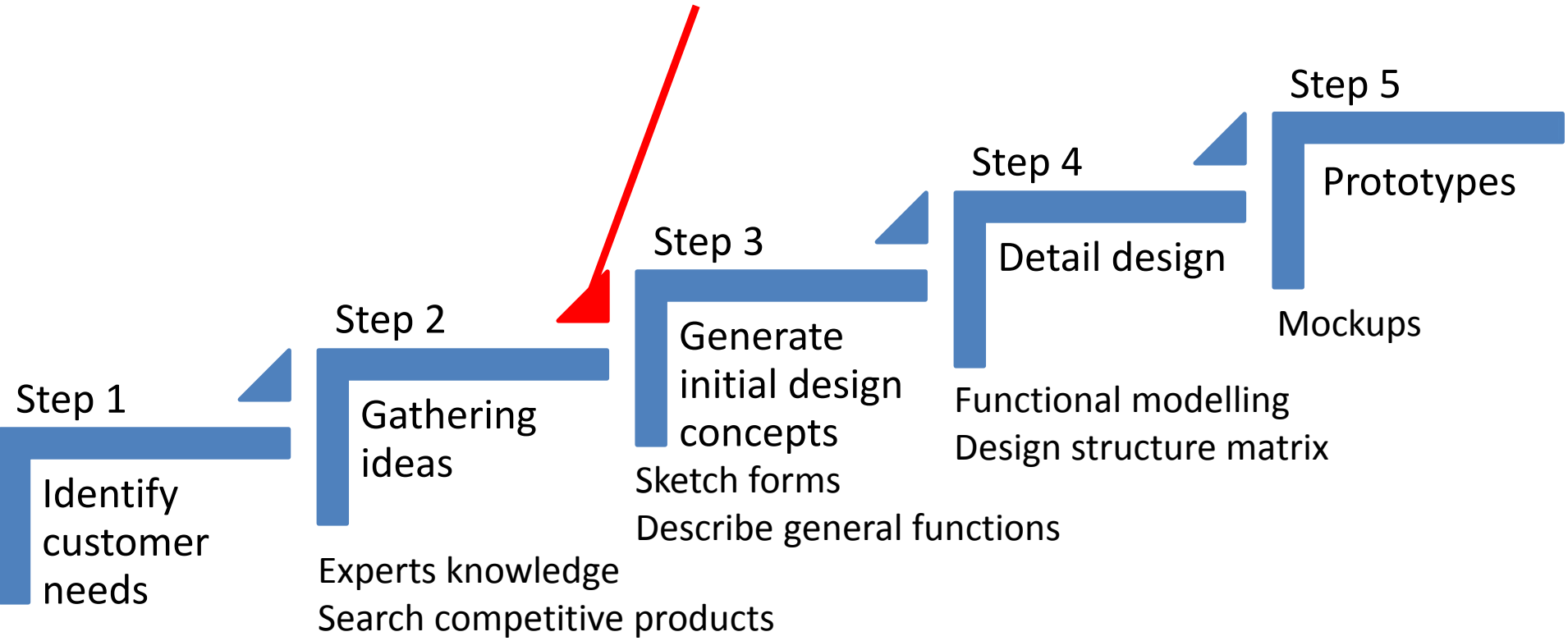
$$Hypothesis: \Delta(X) < \Delta(Y)$$

Related Research

Literature Review

Models	Definitions	Limitations	Ref.
Single Domain Predictive Morphing	Generate design concepts by partially changing current products	Design fixation occurs	[12-21]
Design by Analogy	Discover novel design concepts by exploring analogy across designers' knowledge/ product descriptions for reducing design fixation	Require experts knowledge to discover concepts	[25-30]
Bio-Inspired Design	Discover novel design solutions by taking account into biological domains as design sources	Require deep understanding of Biological domains	[22,23], [31-33]
Functional Model	Generate functional structure based on design concepts from previous sections	Require to select candidate modules with designers' functional knowledge	[34-46],

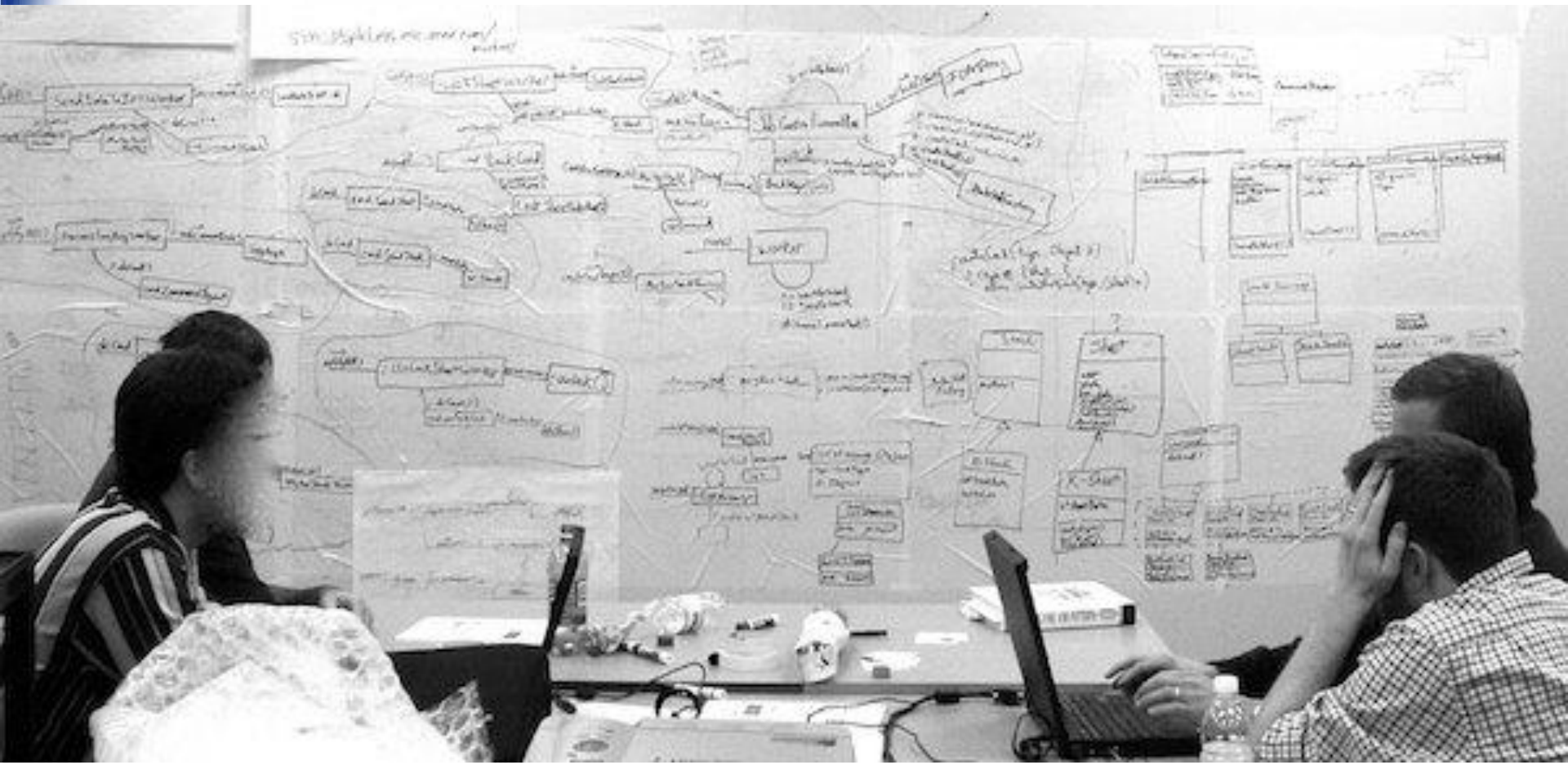
Knowledge Gap



Hsiao and Chou, 2004

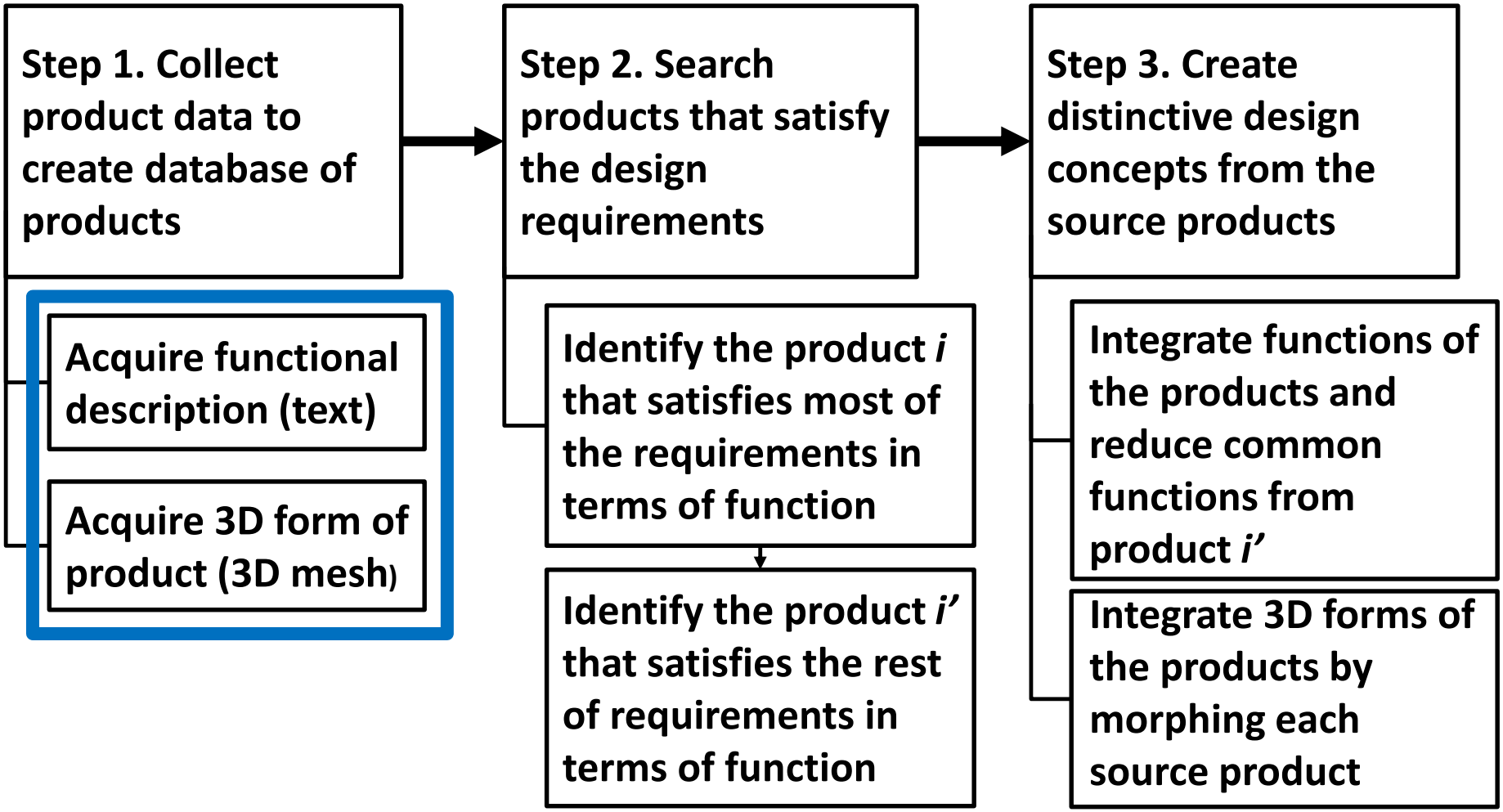
Methodology

The initial step of product design



Designers describe requirements in texts

Overall process of the proposed methodology



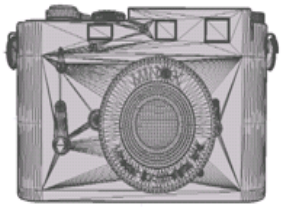
Collect product data to create database of products

Function:

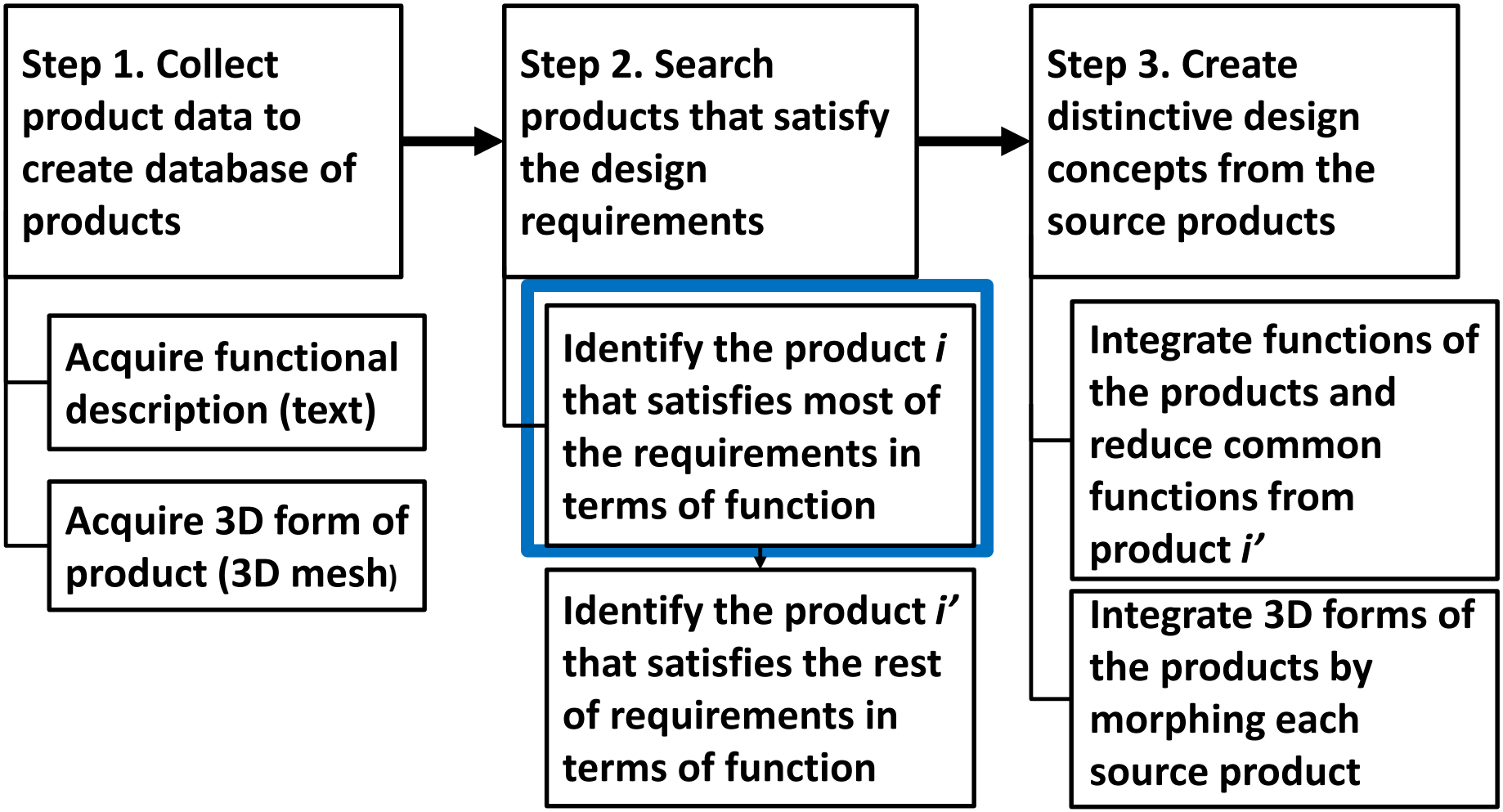
representing the objective of a design artifact.

Form:

representing the geometric surface of a design artifact.

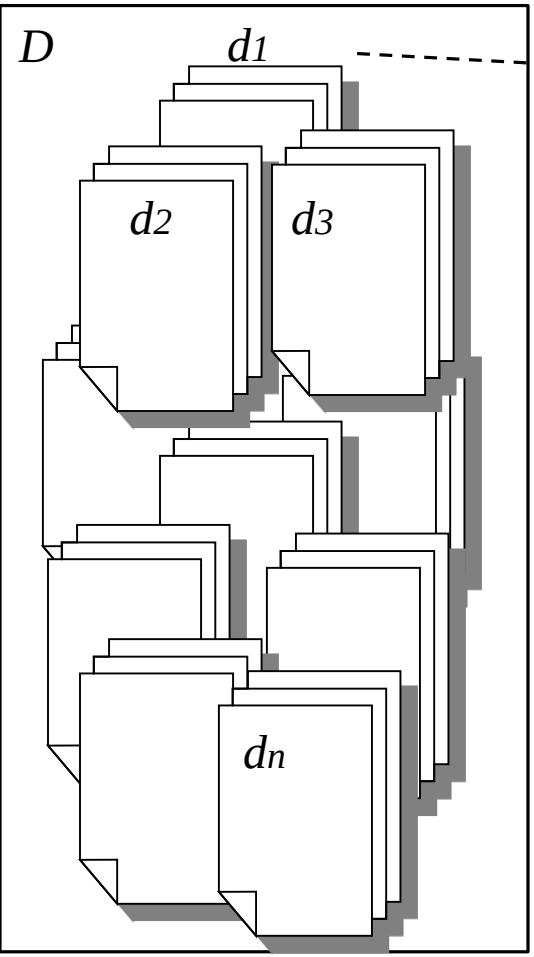
ID	Product Name	Form data (3D mesh)	Function data (text)
1	Camera		Live view shooting, Zoom, White balance, Focus
2	Cell phone		Voice communication , GPS navigator
...	...	...	...
n	...	...	...

Overall process of the proposed methodology



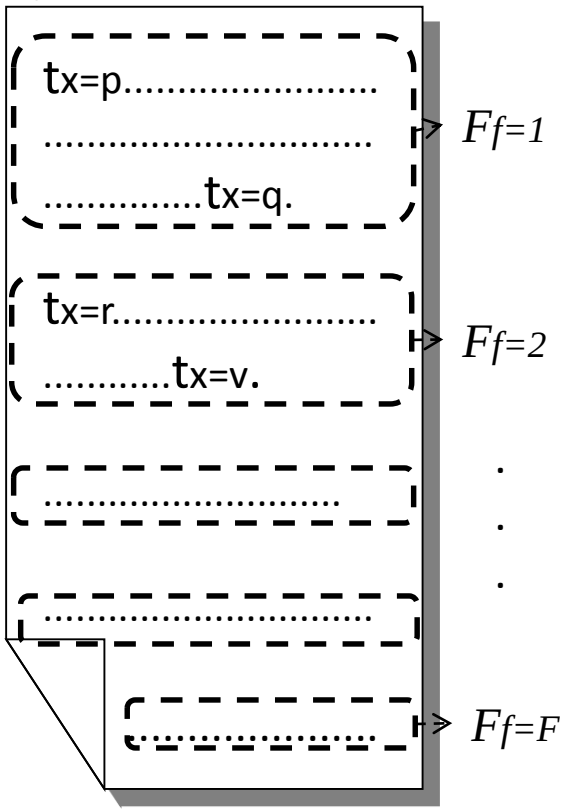
Identify the Product *i* that satisfies most of the requirements in terms of function

Collecting descriptions



A functional description

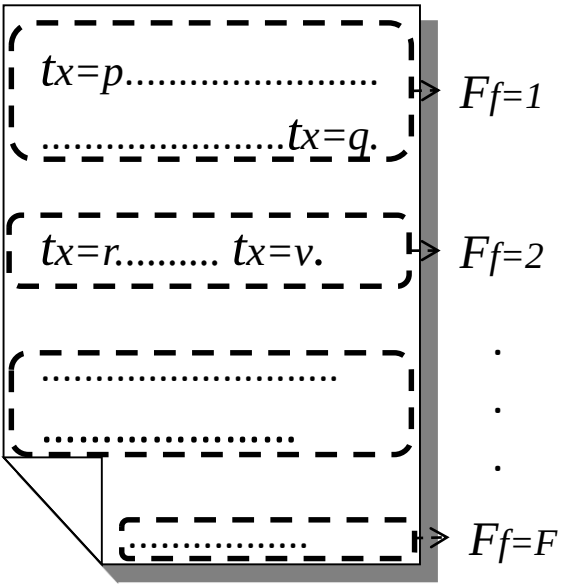
di



A database containing functions of product

ID (i)	Product	Description (d_i)
1	Camera	Encodes digital image and… store… memory…
…	…	…
n	…	…

Identify the Product *i* that satisfies most of the requirements in terms of function



Product (*i=1*)	Description ($d_{i=1}$)
Camera	Encodes digital image and… store…

LDA

	$t_{1,1}$ = image	$t_{1,2}$ = encode	…	$t_{1,F}$ = …
$P(t_{i,f}\|d_i)$	0.16299	0.10111	…	…

$$P(t_{i,f} \mid d_i) = \sum_{f=1}^{F} P(t_{i,f} \mid q_f) P(q_f \mid d_i) \quad (1)$$

where,

$t_{i,f}$: the functions that can found in a textual description of product (i)

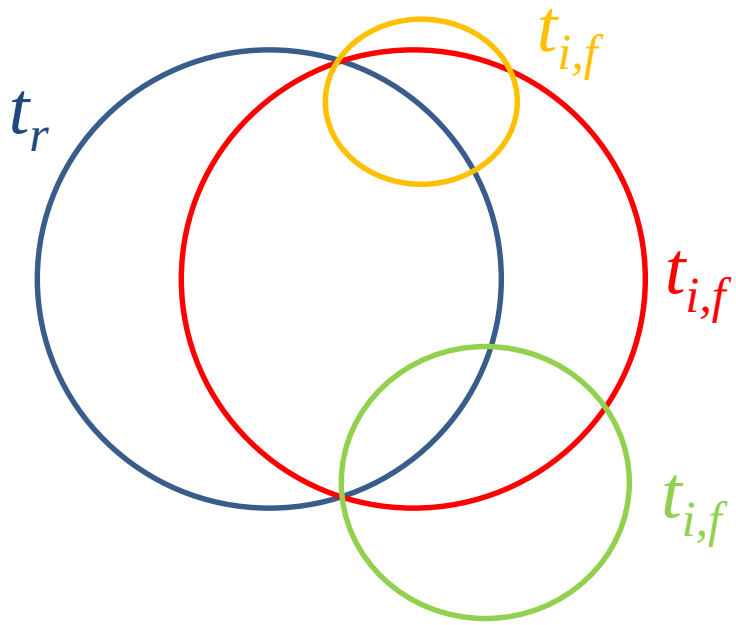
d_i: the textual description of product (i)

q_f: f^{th} *function* (paragraph) in the textual description of product (i)

F: the maximum number of *functions* of product (i)

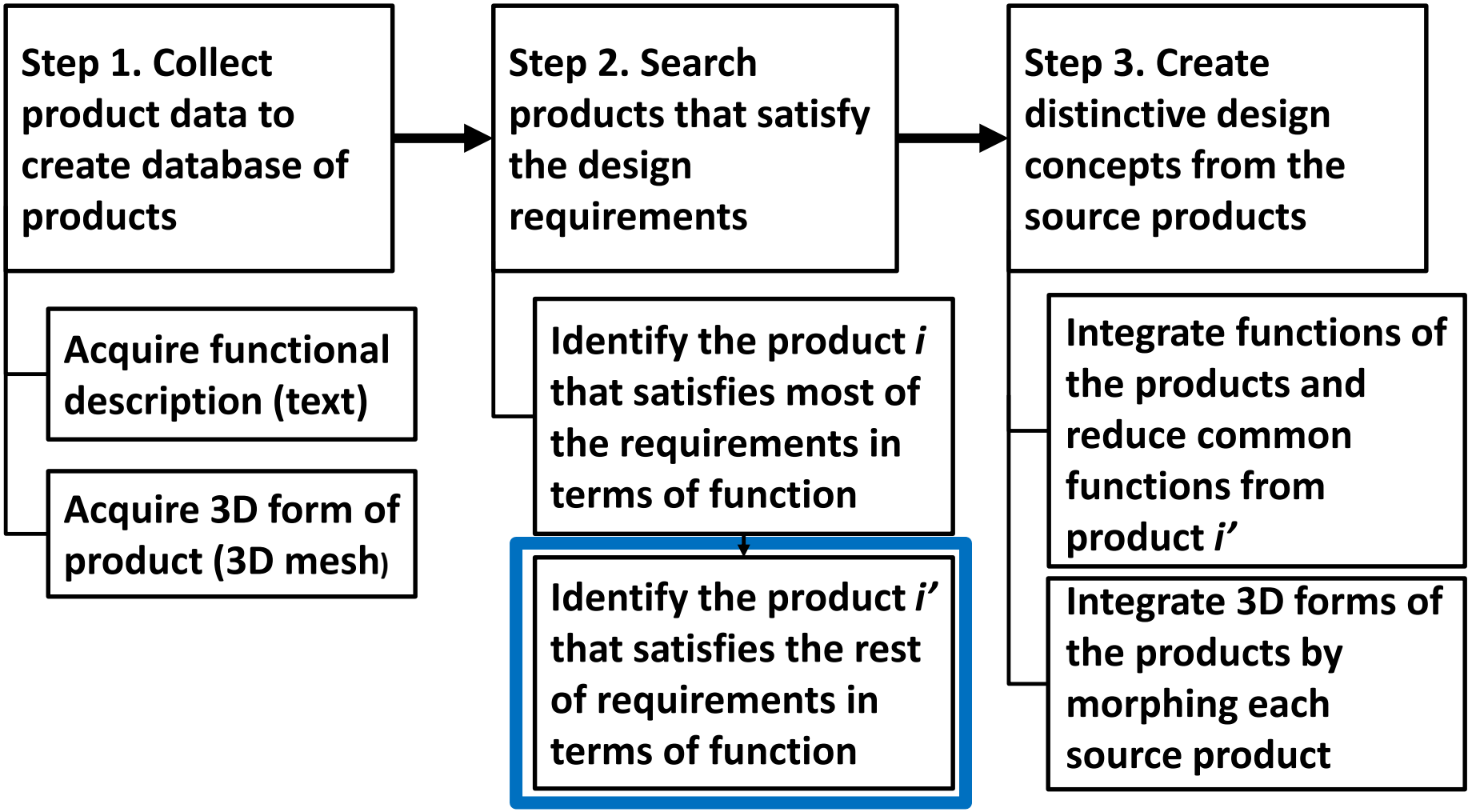
Identify the Product *i* that satisfies most of the requirements in terms of function

$$Sim(t_r, t_{i,f}) = \frac{t_r \bigcap t_{i,f}}{t_r \bigcup t_{i,f}} \quad (2)$$



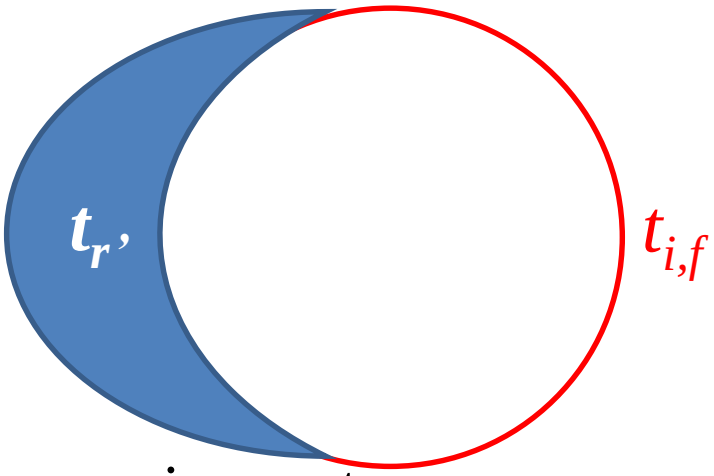
$t_{i,f}$: the functions that can found in a textual description of product (i)
t_r: the terms that can be found in designers' requirements.

Overall process of the proposed methodology



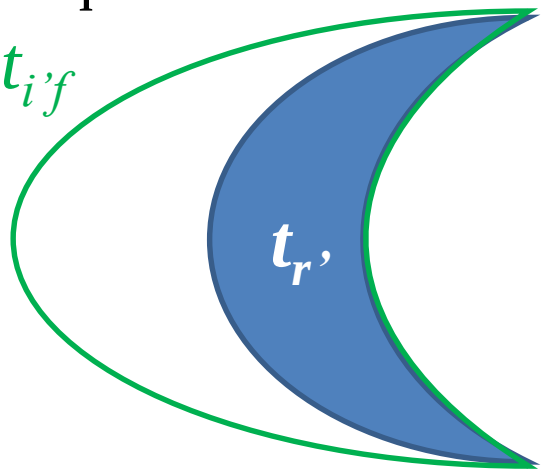
Identify the Product *i'* that satisfies most of the requirements in terms of function

$$t_{r'} = t_r \bigcap (t_r \bigcap t_{i,f})^c \qquad (3)$$



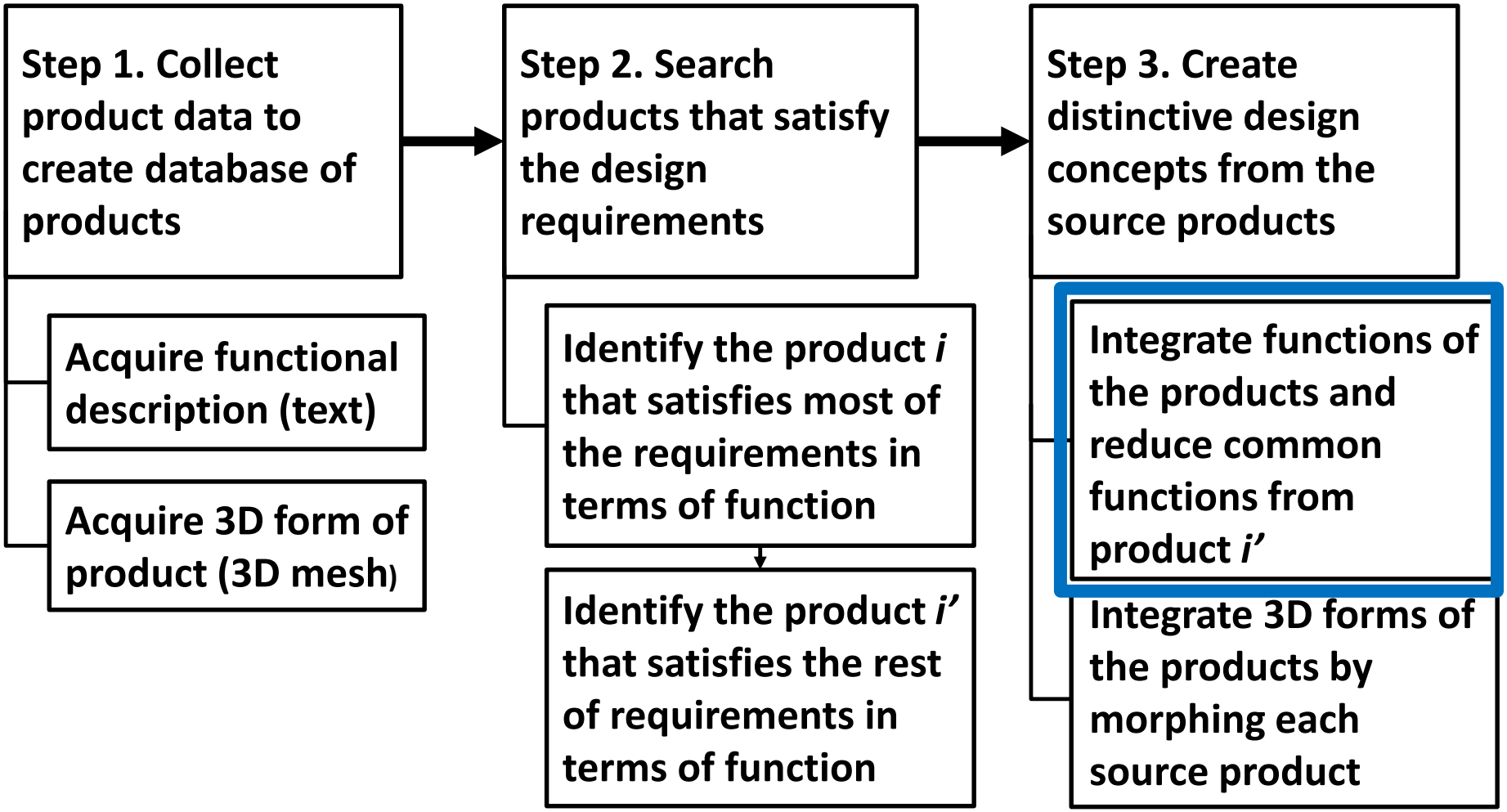
$t_{r'}$: the rest of terms that can be found in the requirements.

$$Sim(t_{r'}, t_{i',f}) = \frac{t_{r'} \bigcap t_{i',f}}{t_{r'} \bigcup t_{i',f}} \qquad (4)$$

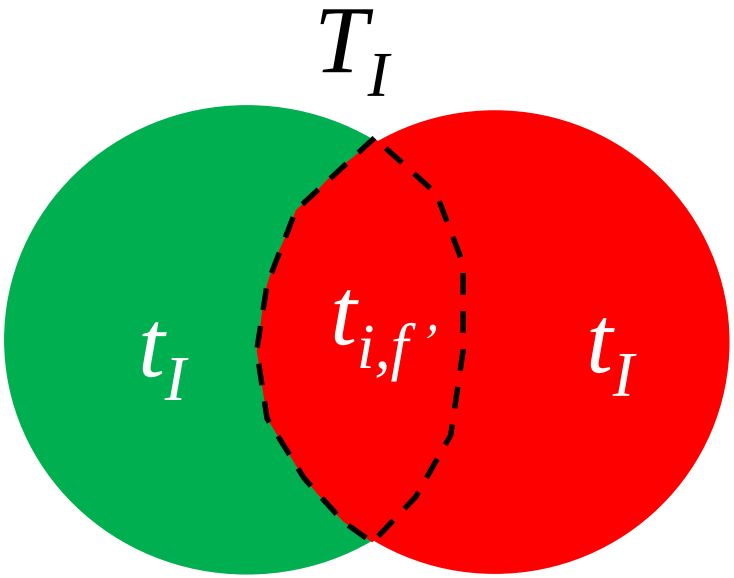


$t_{i',f}$: the functions that can found in a textual description of product (*i'*)

Overall process of the proposed methodology



Integrate functions of the products and reduce common functions from product *i'*



$$F(T_I) = t_I \bigcup t_{i,f'} \quad (5)$$

where,

$$F(t_I) = (t_{i,f} \bigcup t_{i',f}) \bigcap (t_{i,f'} \bigcup t_{i',f'})^c \quad (6)$$

T_I the integrated *functional* terms from each product

t_I: the *functional* terms having no common *functional* terms between each product

subject to,

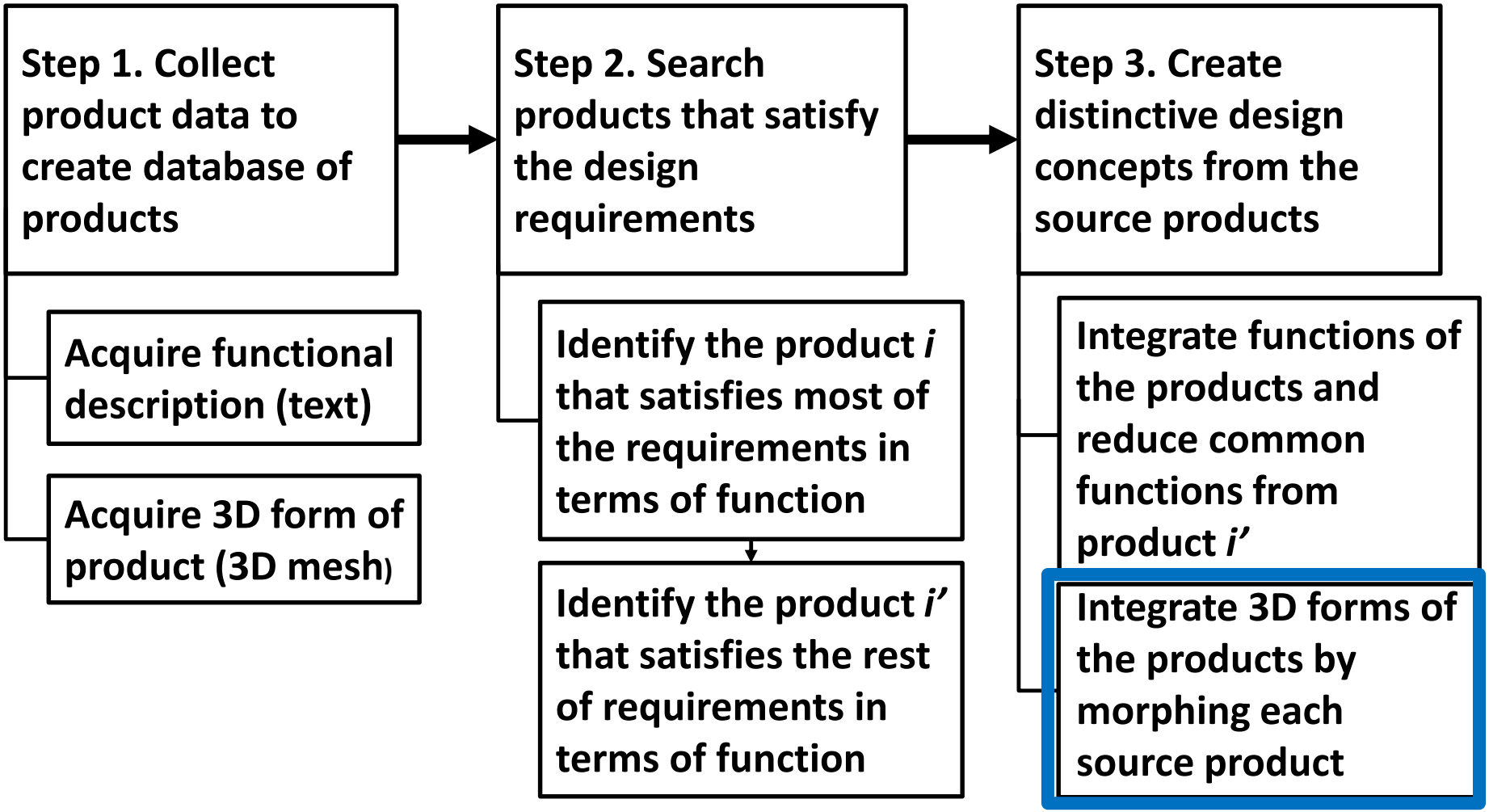
$$t_{i,f'} \subset t_{i,f} \quad (7)$$

$$t_{i,f'} \subset t_{i,f} \bigcap t_{i',f} \quad (8)$$

$$t_{i',f'} \subset t_{i',f} \quad (9)$$

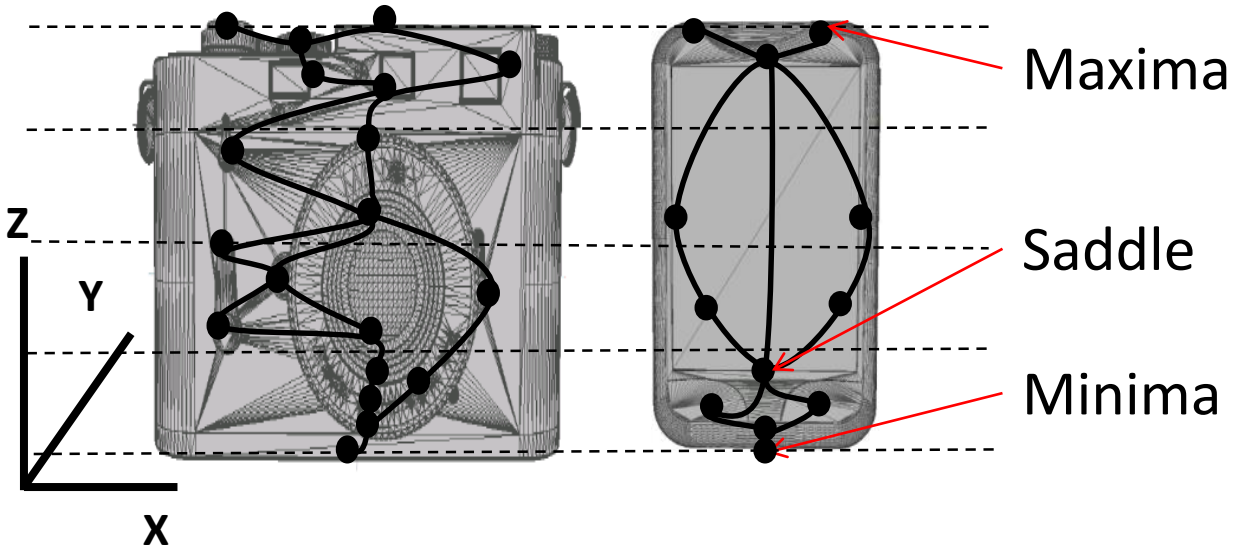
$$t_{i,f'} \subset t_{i,f} \bigcap t_{i',f} \quad (10)$$

Overall process of the proposed methodology



Integrate 3D forms of the products by morphing each source product

Generate Reeb graph for each source and target 3D model [44]



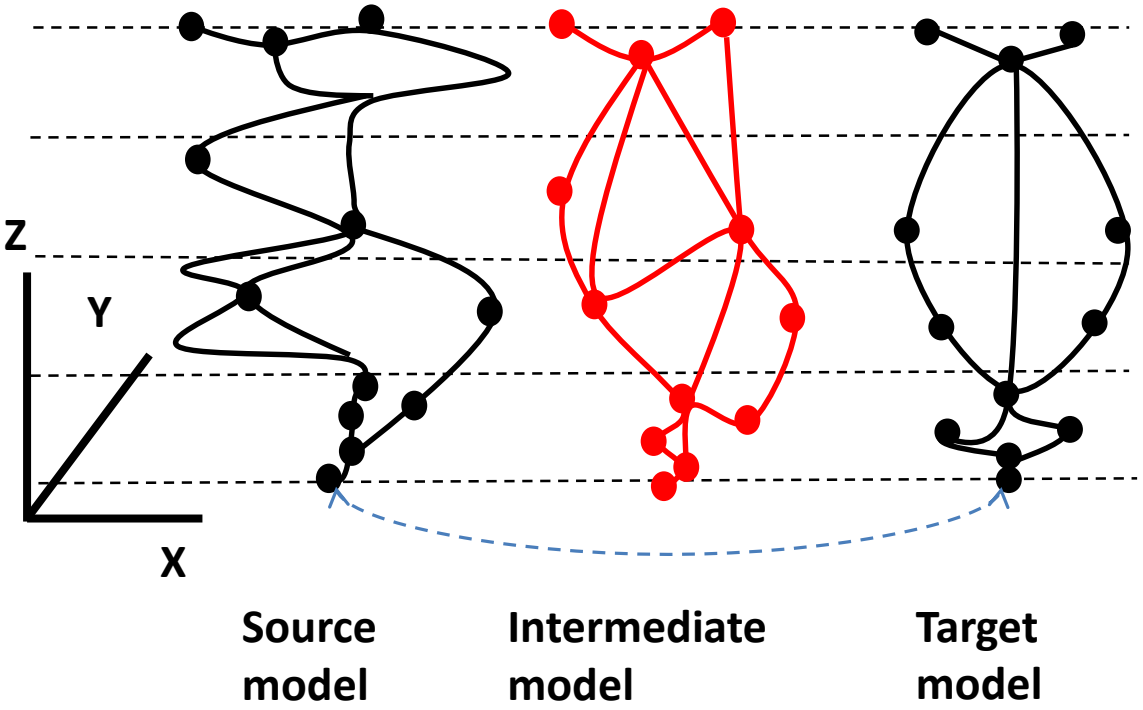
Similarity ratio =

the number of matched points in the level sets /

the number of larger data sets

Integrate 3D forms of the products by morphing each source product

Generate an intermediate model



Case Study

New Product Development

-application

Design Scenario

Designers want to explore additional domains to search novel design concepts that can lead to the development of novel differentiated products in the marine domain.

New Product Development

-application

Design Scenario

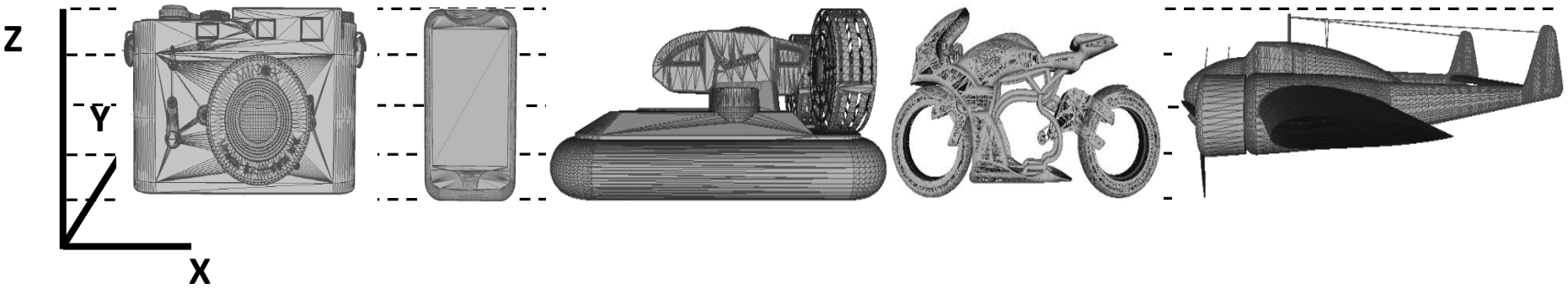
Designers have described the functional requirements for novel product domains

- It will be a vehicle
- It will operate over water
- It will not be influenced by waves
- It will operate over land
- It will move with stability
- It will be able to use the ground effectively
- It will be able to fly

New Product Development

- data collection

Form:



Digital camera | Cell phone | Hovercraft | Motorcycle | Airplane

Function:

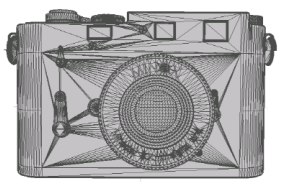
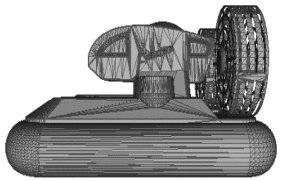
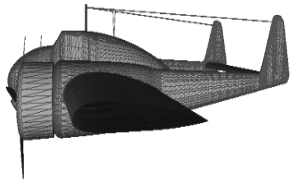
"A digital camera has a compressor and decompressor to provide for raw sensor data to be stored more compactly prior to image processing…"

"The cellular phone system according to the present invention separates one or more of such components…"

New Product Development

- Search candidate products

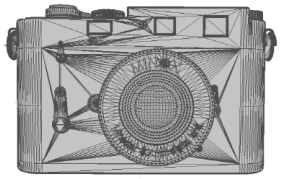
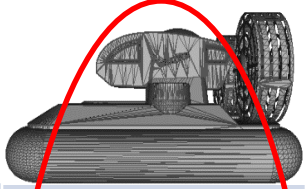
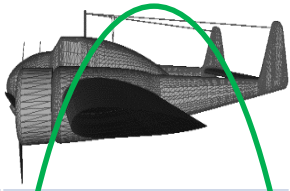
Functional probabilities (%) from each product corresponding to the requirements

Requirements (t_r) \ Product					
vehicle	0%	0%	1%	6%	0%
water	0%	0%	2%	0%	0%
wave	0%	0%	1%	0%	0%
land	0%	0%	1%	1%	2%
stability	7%	0%	0%	14%	3%
ground-effect	0%	0%	9%	0%	0%
flight	0%	0%	0%	0%	4%

New Product Development

- Search candidate products

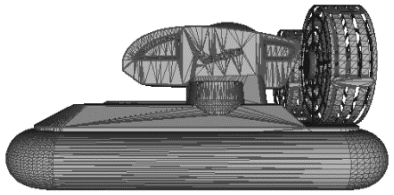
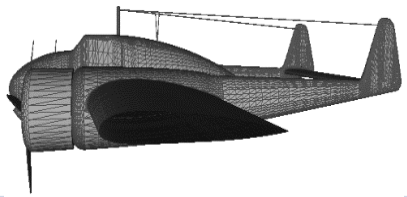
Functional similarity between the requirements and products

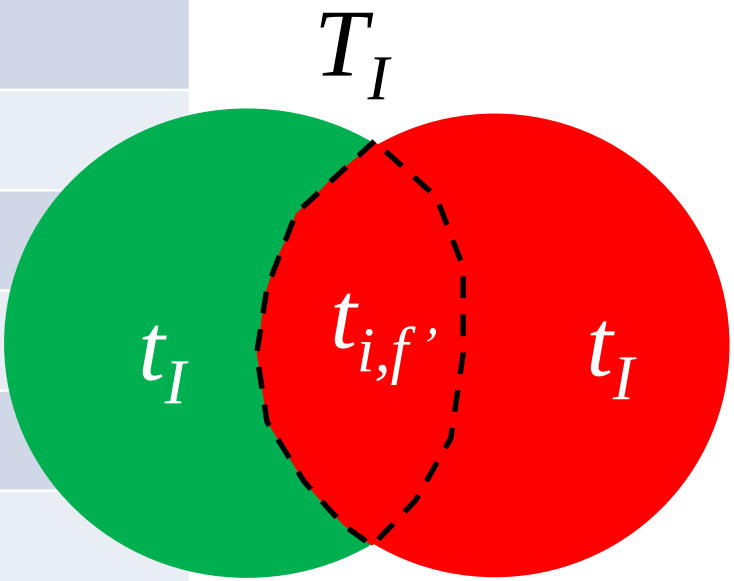
Product (i)					
Functional similarity	**5% (1/14)**	**0% (0/25)**	**21% (5/22)**	**13% (3/19)**	**4% (3/67)**
vehicle			✓	✓	
water			$t_{i,f}$ ✓		$t_{i'f}$
wave			✓		
land			✓	✓	✓
stability	✓			✓	✓
ground-effect			✓		
flight					✓

New Product Development

- Functional concept generation

Common functions between the products

Parent products overlapped functions		
turbine	**2%**	**7%**
propeller	**4%**	**3%**
aerodynamics	**1%**	**1%**
maneuverability	**1%**	**2%**
absorber	**2%**	**1%**
cargo	**1%**	**1%**

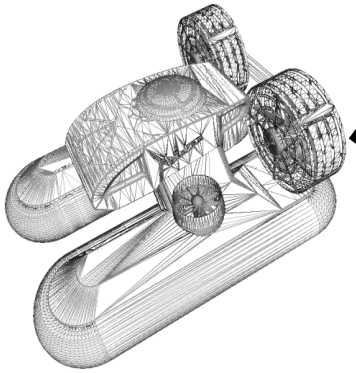


the functional concepts for novel product domain = the hovercraft's 22 functions + airplane's 61 functions

New Product Development

- Form concept generation

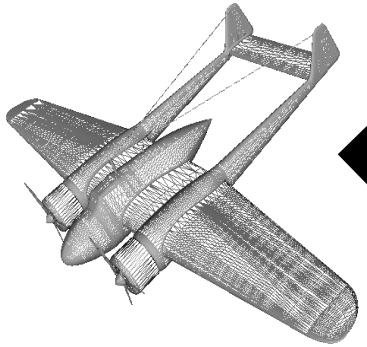
Hovercraft



Design concept of the hybrid marine model

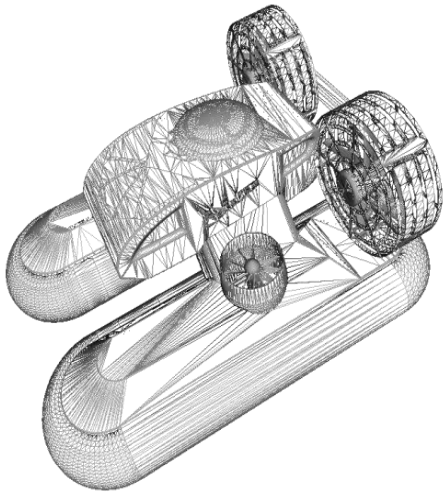
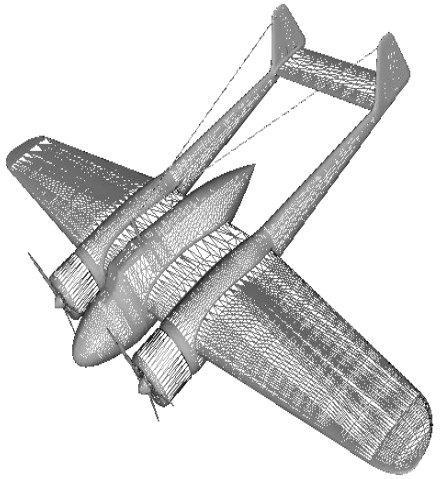
Morph

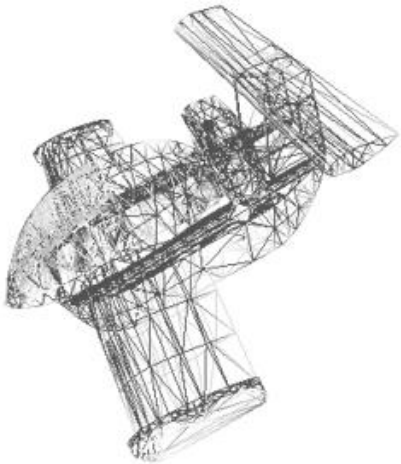
Airplane



New Product Development - verification

Form and function similarity between wig and models

form similarity (x)			
function similarity (y)	**x = 61%** **y = 30%**	**x = 17%** **y = 23%**	**x = 47%** **y = 9%**



Conclusions

Summary

Differentiated design concepts are generated from source products by reducing their similarity during the combination process in terms of *form* and *function.*

The experiment of the methodology demonstrates the possibility of an automated concept generation process that combines different products that satisfy designers' requirements

Future work

Future work

Improving the generated concepts into detailed engineering specifications by employing function-behavior-structure (FBS) model

Analyzing the interaction between *form* and *function* by related domain expertise will provide sophisticated design concepts to designers

Q & A

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