12TH INTERNATIONAL DEPENDENCY AND STRUCTURE MODELLING CONFERENCE, DSM'10
22 – 23 JULY 2010, CAMBRIDGE, UK

PLANNING SUPPORT OF INITIAL DESIGN PROCESS BASED ON GROUPING AND ORDERING OF TASKS: DESIGN EXAMPLE OF AN INTEGRATED CIRCUIT

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Keywords: product development management, design process, constraint network, task planning, design structure matrix, Dulmage–Mendelsohn decomposition

1 INTRODUCTION: MOTIVE FOR AND OBJECTIVE OF THIS RESEARCH

1.1 Importance of and difficulties in deriving a design process

Product-development requirements are becoming more complicated by moving away from the simple pursuit of higher performance and lower production costs as customers' requirements become more diverse. For example, needs vis-à-vis the development of large-scale integrated circuit (LSI) have changed, from pursuing the limits of miniaturization to attaining solutions by which diverse needs—such as applications for small electronics devices like mobile phones, home electronics like televisions, and automobiles—can be met.

Companies face the need to change design processes in a flexible and logical manner, to cope with these changes in requirements. Here, "design process" refers to a series of flows used to decide product specifications that satisfy requirements; it is described by the design task that best fulfils jobs and by the order that illustrates the anteroposterior relationship among the design tasks. We need to establish a method of deciding upon a design process that can address each requirement flexibly.

1.2 Research on the planning support of a design process

(i) Structuring the Design Process using DSM

In DSM (design/dependency structure matrix), the dependency relations are expressed in a matrix, which is then used to describe, visualize, determine and maintain the entire design process. Lately, DSM-based methods have been proposed to visualize design processes, reducing rework, (Eppinger, 2001) consider the constraints of resources (Miao, 2004), and evaluate robustness (Yassine, 2001). They are also used to analyze for the possibility of defects and to evaluate the process in terms of demands and confirmation. (Yang, 2005; Nakazawa, 2006).

Existing DSM-based methods are mainly used to overview and understand the present design process and detect the feedback loop, using the results of interviews with each engineer and information on documentation flow. Because such methods mainly focus on applications related to the relatively lower stream in product development, they are designed for situations where the input–output relations of tasks that constitute the design process are generally clear. It is difficult to apply DSM effectively to a review of an entire design process, if the objective is to address a new requirement on the part of the target customer; this is because the input–output directions are not fully established, and it is difficult to detect the feedback loop in the early design stage.

(ii) Derivation Support for a Design Process using DM Decomposition

We can introduce the Dulmage–Mendelsohn (DM) decomposition (Dulmage, 1962) as an applicable method to extract the design process from a stage where there are no influential directions between factors. Yoshikawa et al. (2004) propose a method that extracts a stepwise process from a complicated system, using DM composition.

The proposal by Yoshikawa et al. derives the order in design by extracting the process group equivalent to the task, using the mathematical method of maximum matching. As this research indicates, grouping tasks is an effective approach for analyzing a design process within a stage where no influential directions have been decided. In fact, one must consider a tremendous number of design process plans if many tasks exist, because task orders equivalent to at least $O(2^n)$ are probable against the number of tasks n.

However, the research by Yoshikawa et al. derives the design order while focusing ***only*** on matters related to factors and processing; it does not emphasize design information, like the ***functions*** or ***structure*** of a product. In reality, however, the design group should frequently defer to viewpoints regarding the functions and structure of a product. This study discusses only a few research activities that have focused on approaches to grouping trials; such research is undertaken from the viewpoint of the functions and structure of a product, rather than from using mathematical processing.

1.3 Problems therein and focus point of this research

In this research, we focus upon the following two points by analyzing the results of existing research.

(i) Grouping Tasks from Functional and Structural Viewpoints

There has been a tendency to group tasks, with a special emphasis on mathematical processing. In this study, however, we consider it necessary to undertake specific grouping from the viewpoint of product function and structure. The researchers propose a product information model (Koga, 2009) that can describe the design function and structure of a product; we presume that the proposed product information model will enable us to group tasks and decide the grouping order, taking into consideration information on the function and structure of a product.

(ii) Deciding Order When There Are Undecided Input and Output Tasks

Existing methods represented by DSM visualize and improve the present process on the basis of the input–output relations of tasks. For the scenario discussed in this study, however, we need to examine the design process in situations where the design process and the input–output relations influence each other. We thought that a simultaneous consideration of the design process and input–output relations would make the problem overly complicated. Noting that our method ultimately aims to create a design process, we thought it more efficient to search for and evaluate the order of tasks first and subsequently set appropriate input–output relations in the design processes that had been judged favorably.

1.4 Research objective: planning support for a good design process

This paper looks to support the derivation of a better design process within the early design stage, where the input and output of a task are not decided. We recognized that a good design process needs to consider the following two viewpoints.

(i) Good Task-grouping

- Each group involved has the intention to read and understand design plans from functional and structural viewpoints.
- Consideration is given to reducing the amount of influence between groups, and an optimized, whole-product design is recognized by undertaking independent design activities.

(ii) Good Order of Task-processing

- The design order should not involve a large number of design-rework and modification risks.
- The remaining areas—in which a rework is inevitable—should be clearly specified.
- Important values can be decided in the upper stream of design, where designers have a relatively high degree of freedom.

These two viewpoints are supposed to influence each other. Through them, we tried to derive a good design process by examining the group and the overall process bilaterally.

2. MODEL: PRODUCT INFORMATION AND MODELING-DESIGN PROCESS

2.1 Design and interpretation of the design process

Various constraints exist between attribute values, and they should also be considered in terms of the design attributes. In this study, we specified the process and set all attribute values so that they did not contradict each other within the design process.

2.2 Representation model for product information

In this study, the product information model consists of the following four pieces (i)–(iv) of information, each of which the designer must enter.

(i) Information on the Component Formation of a Product

(ii) Attribute Value of Each Component

(iii) Constraint Equation between Attributes

(iv) Design Requirements

3. METHOD: HOW TO DERIVE THE DESIGN PROCESS

3.1 Flow chart and information processing in deriving the design process

To make decisions regarding the design process, we propose the use of a method that helps one efficiently select a good design process plan from the enormous solution space available, following a procedure that continues with grouping, ordering, evaluation, and task selection, in that order. Fig. 1 provides an overview of information processing.

3.2. Grouping constraints and a search algorithm for the order

In search for a constraint order, as shown in Fig. 1(1), the process continued with the grouping of constraints, followed by the search, evaluation, and selection of the constraints order according to the following two viewpoints: (i) Process Return Risk, (ii) Decision-making Efficiency.

3.3 Search for the design process

On the basis of the decided constraints' design order, we decided upon the input–output relations of the constraints, so that they could satisfy the constraints' design order, as shown in Fig. 1(2).

3.4 Target-setting and the redesigning of a group, using order information

On the basis of the selected design process, in Fig. 1(3), we evaluated whether the group decided at the beginning of method deployment was appropriate for the inside of the design process.

As the inside of the design process is an appropriate point of observation for evaluating the appropriateness of the group, we explored the possibility of setting the group's own target as the prerequisite.

A target set within a group also serves as a "promise" for other groups. If the target attribute is set successfully, indirect influences among the groups decrease. Given this factor, we searched for the attribute that could decrease, as much as possible, influential relations among groups; that attribute was set as the target of each group. We modified groups that could not specify an appropriate target by way of division and integration, as they are supposed to encounter problems regarding particle size.

4. RESULT: IMPLEMENTATION AND DISCUSSION USING LSI EXAMPLE

We implemented the aforementioned derivation method for the design process in LSI design, using Smalltalk; we subsequently applied it to the design of LSI. The LSI we used as product information had 13 layers, 30 entities, 170 attribute values, and 100 constraints. Accordingly, there were 379 links between attribute values and constraints, and the constraints had a total of about 10114 combinations of input–output directions. All product information was obtained by surveying the papers and interview of the professional engineer.

We confirmed the effectiveness of the proposed method by comparing its result (Fig. 2, Plan D) to that derived by not applying the method (Fig. 2, Plan A). We also assessed the effectiveness of each operation by comparing the result of the method to that derived by applying the method only partially.

Deciding grouping and ordering in a random manner—instead of relying upon the proposed method—resulted in complicated design process plans that prompted many reworks (Fig. 2, Plan A). The implementation of a process plan that employed only one of the two kinds of optimization—namely, grouping and ordering—resulted in a rework on the part of attribute values (Fig. 2, Plans B–C). Unlike Plan D, Plan B left dependency relations that caused a rework, as shown within the columns in Fig. 2, owing to its inability to band attributes related to many constraints within the same group. This supposedly indicated a rework due to an inefficiency caused by the division of labor.

Unlike Plan D, Plan C left dependency relations that caused a rework, as shown in the rows in Fig. 2, showing that attributes that are always in need of modification are left from the upper to the lower design streams. Reworks due to an inefficient process procedure that leaves behind these attributes are inevitable. As shown by Fig. 2, Plan D, we successfully derived an appropriate design process plan that decreases the risk of a large rework, by applying the proposed grouping and ordering to an appropriate design.

5. CONCLUSION

In order to find an optimal design process, we conducted 2,000 searches for constraints and 1,000 searches for design processes, out of more than 10114 possible searches. Subsequently, we modified the grouping once and conducted the same search for the same number of times for constraints and for

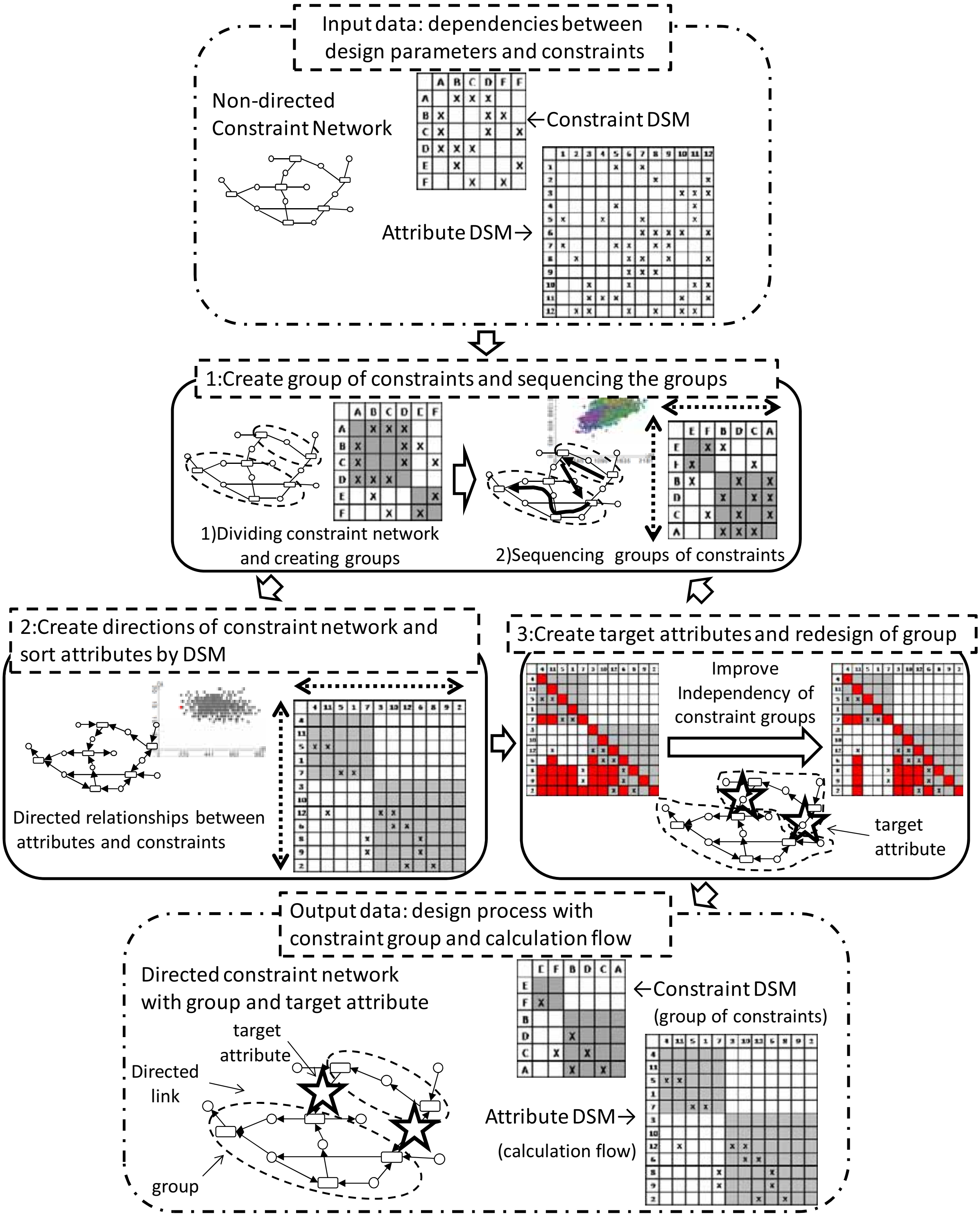

Figure 1. Flow chart and information processing process of proposed method

design processes. By undertaking comparisons and examinations, we confirmed that we could decide upon a design process plan that was capable of reading specific intent.

We compared the design process plans and confirmed that the search for a design process after the implementation of grouping and the search for design process after an evaluation indicator has been introduced play certain roles in the search for a design process that prompts few reworks.

Judging from the above results, the original hypothesis—that an approach in which one starts with the constraint order is efficient—was found to be accurate, and the method based on this hypothesis is therefore expected to have a certain amount of utility.

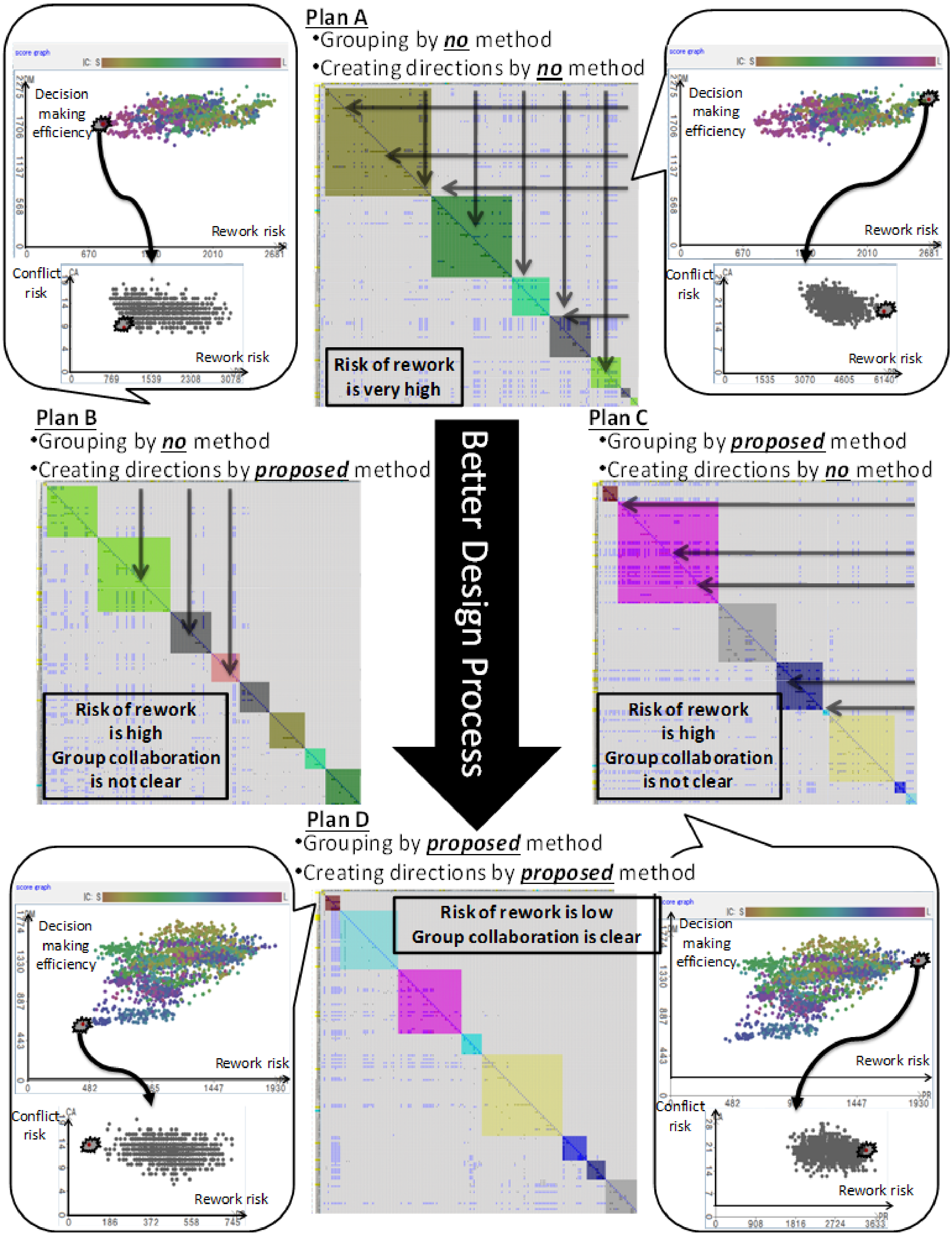

Figure 2. Result of grouping and sorting of tasks in early LSI design process: Comparison between proposed grouping/sorting method and existing method

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Planning Support of Early Design Process Based on Grouping and Ordering of Tasks

Design Example of an Integrated Circuit

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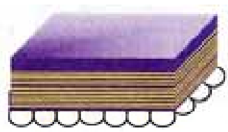
Introduction: Why planning of early design process is important?

- Design of system LSI (Large-Scale Integration, Integrated circuit) involves huge number of constraints in multi-domain problems
  - Ex: heat, electronics, strict size, cost, rapid change of technology, etc.
- Conceptual early design is very important
  - Example of early decisions in design of system LSI
    - Decision of production process rule (size of transistor)
      - 135nm or 90nm or 65nm or 45nm
    - Laminated structure
      - SoC or SiP, 3 layered SiP or 4 layered SiP
  - Detailed design is too complex -> highly automated by computer
- Design process should consider all dependencies between multi-domain problems in important early design stage

Example of early decision:

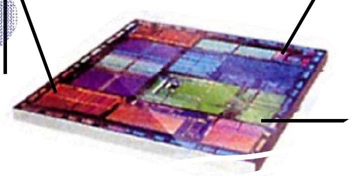
or



SoC: System-On-a-Chip ?   SiP: System-In-Package ?

Planning of design process using DSM

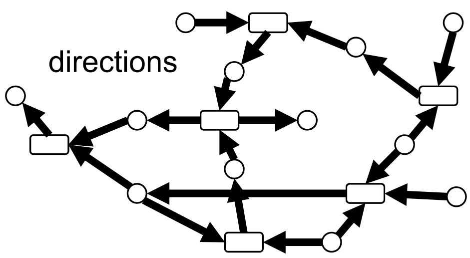
Mounting Board
- Latency time
- Gross area
- Production cost

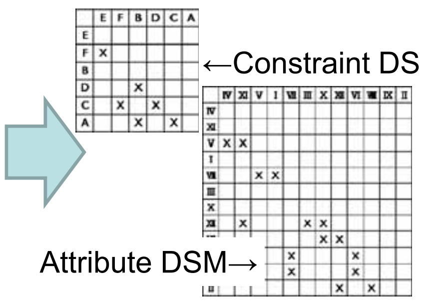


Logic Chip
- Electric requirements
- Process speed
- Number of gates

Memory Chip
- Thickness of chip
- Power consumption
- Defect density

directions





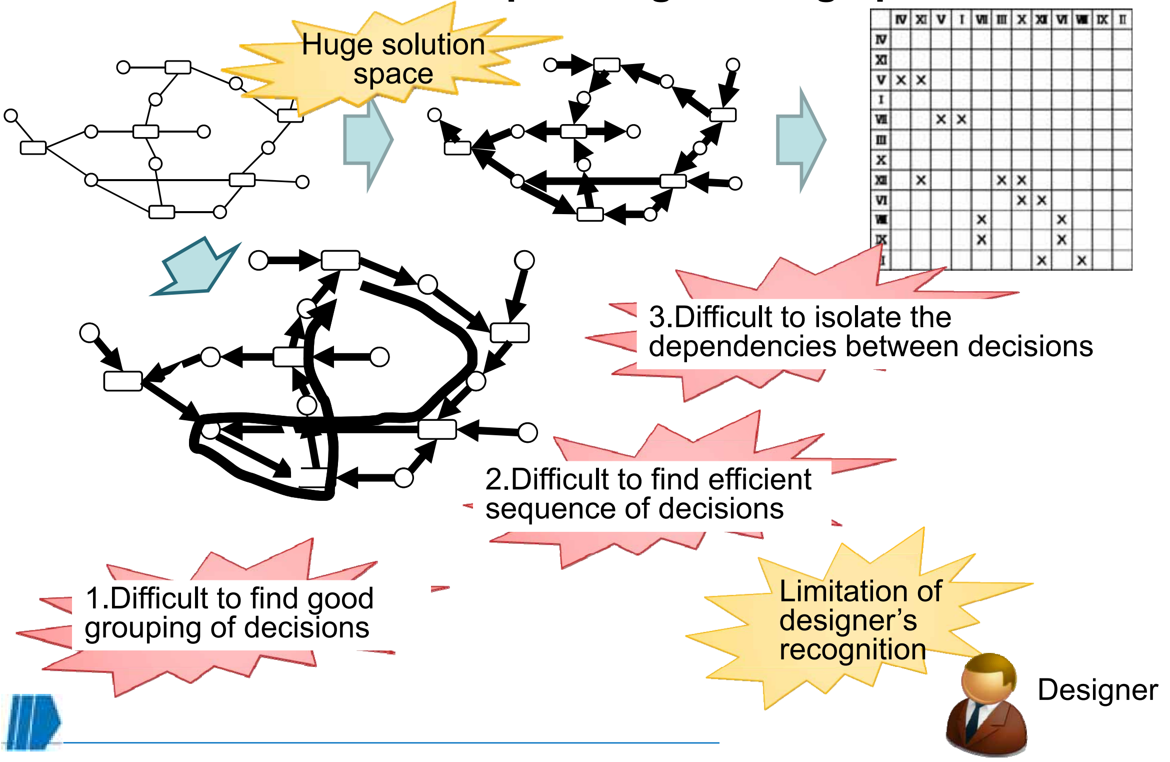
←Constraint DSM

Attribute DSM→

▭ : Constraint (chart, equation, etc.)
○ : Attribute (parameter, shape, etc.)

If directions are given, Design loop is detected and design order is calculated

Three difficulties in planning of design process



What is “good design process?”

- This research assumed that good design process have following three key requisites:

1. Good grouping of design decisions (=design task)
   - Good decisions have meaningful design function
   - Design of complex product can decomposed into decisions

2. Good sequence of design tasks
   - Effective sequence has less design iteration and conflicts
   - Important decision can be done in early stage

3. Good design target of each design task
   - Find good communication point between groups
   - Reduce dependencies in overall design process

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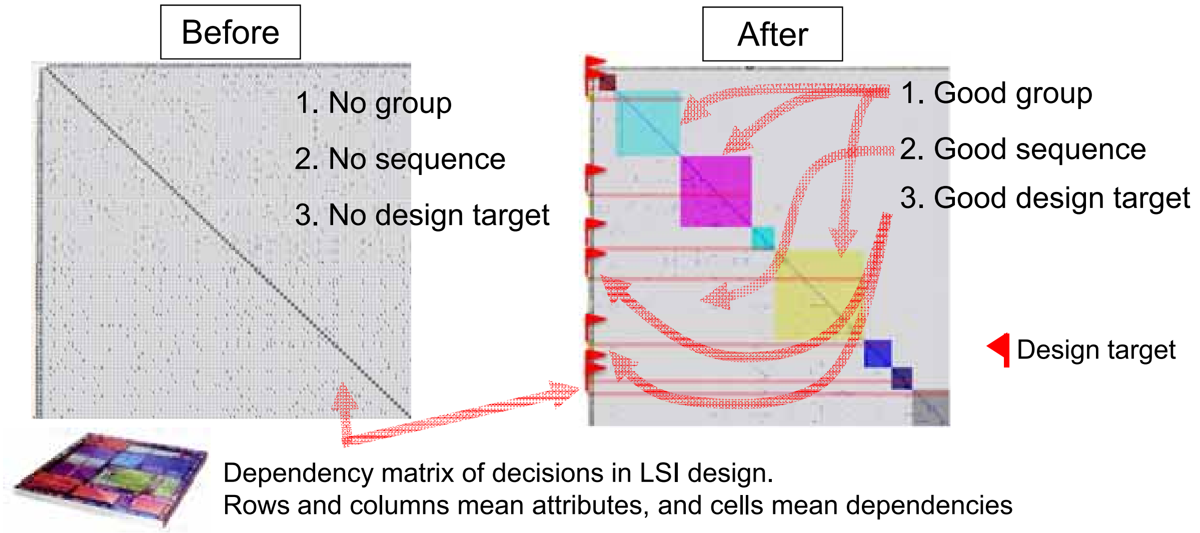
Research Purpose

- Propose planning method of "good design process"
  1. Good group of design decisions (functionally or structurally meaningful)
  2. Good sequence of design decisions (less design loops and conflicts)
  3. Good design target of design decisions (high independency)



Dependency matrix of decisions in LSI design.
Rows and columns mean attributes, and cells mean dependencies

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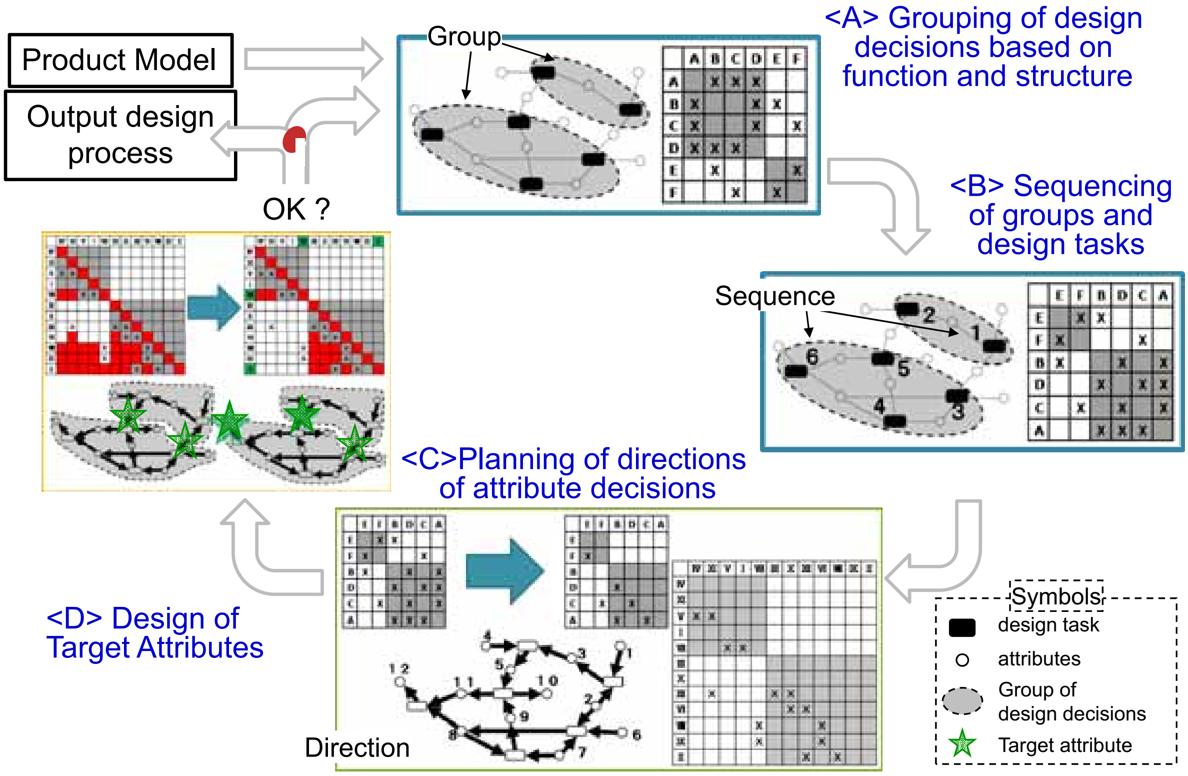
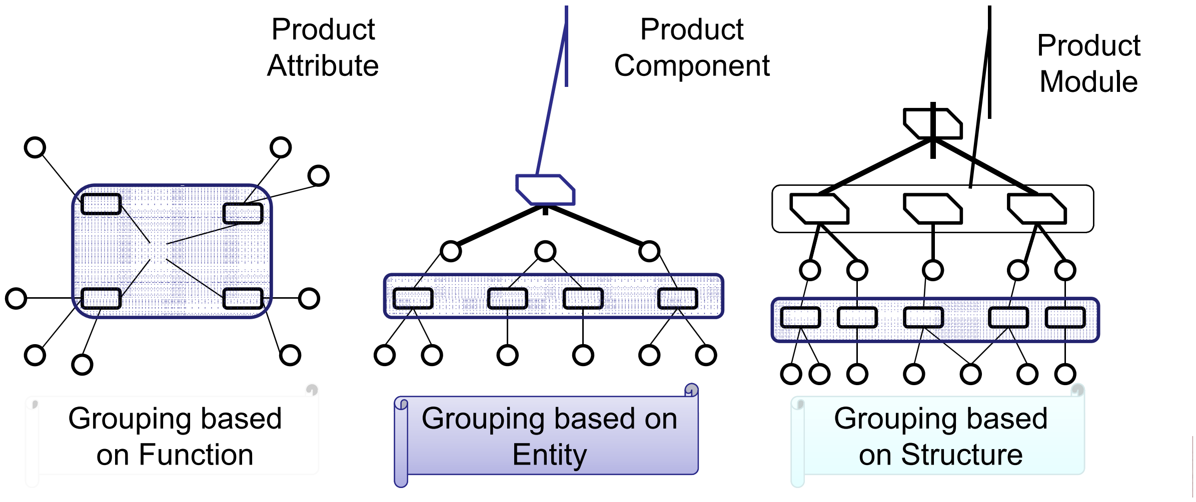
Overview of Planning method of design process



<A> Design task identification based on grouping

- Grouping based on three factors
  - Function: decisions linked to same product function
  - Entity: decisions linked to same product entity
  - Structure: decisions related with same module



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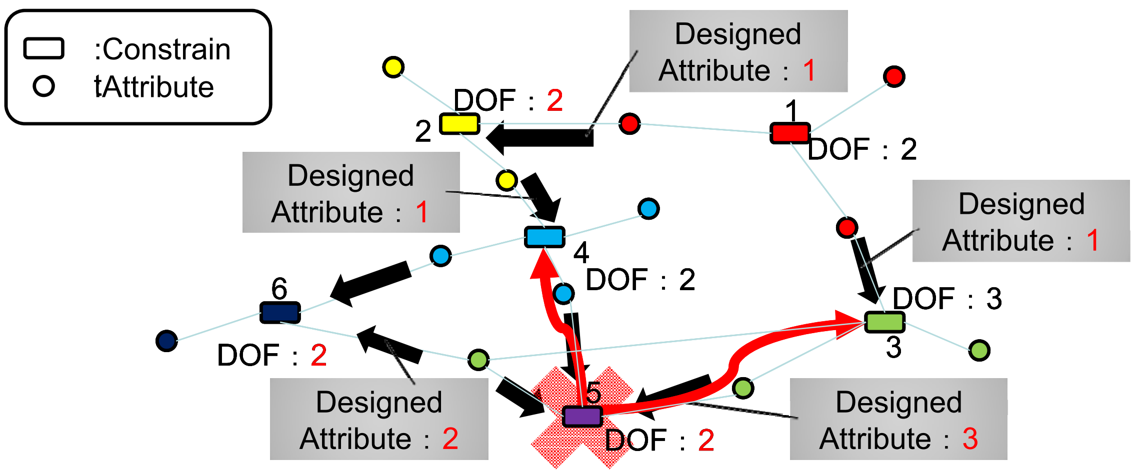
<B> Sequencing of groups and design tasks

- Order of sequence is evaluated by three metrics
  1. Process Return Risk (PR)
  2. Decision Making Efficiency (DM)
  3. Important Attribute Check Risk (IM)

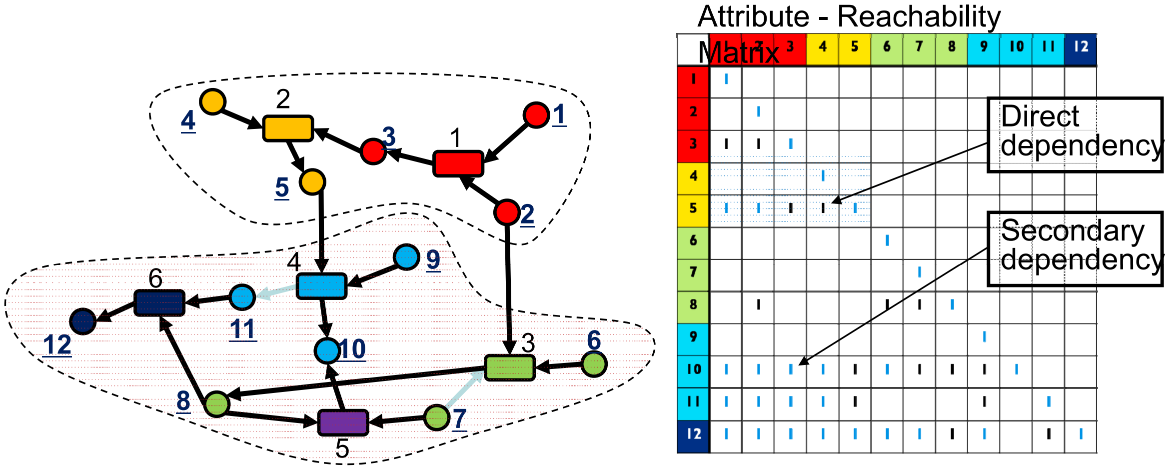


DOF: Degree of Freedom

<D> Design of Target Attributes

- Target attribute is an objective of group
  - Good target reduces secondary dependencies
  - Reduction is achieved using ISM (Interpretive Strucutral Modeling) method

Before applying ISM method



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<D> Design of Target Attributes

- Target attribute is an objective of group
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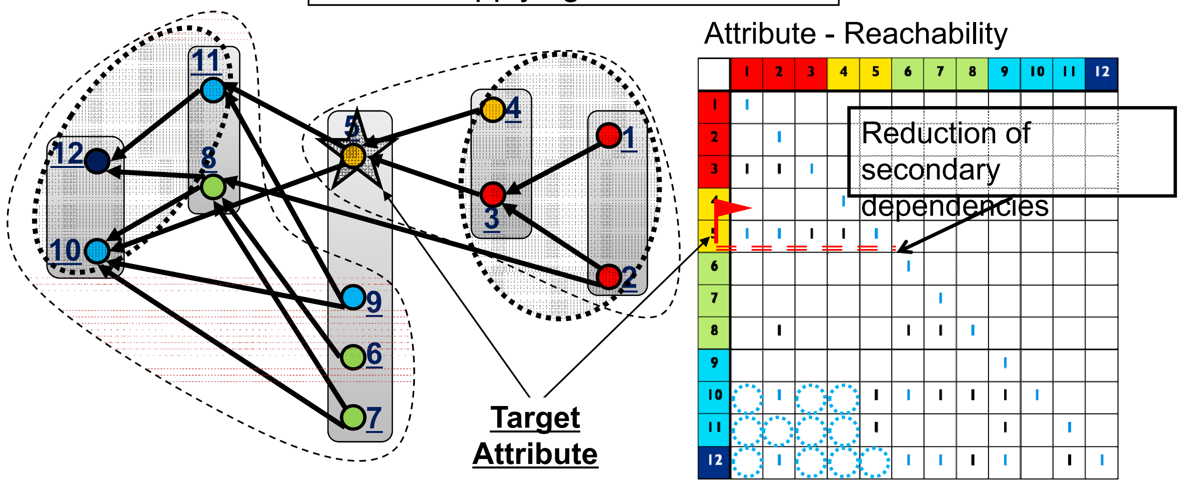
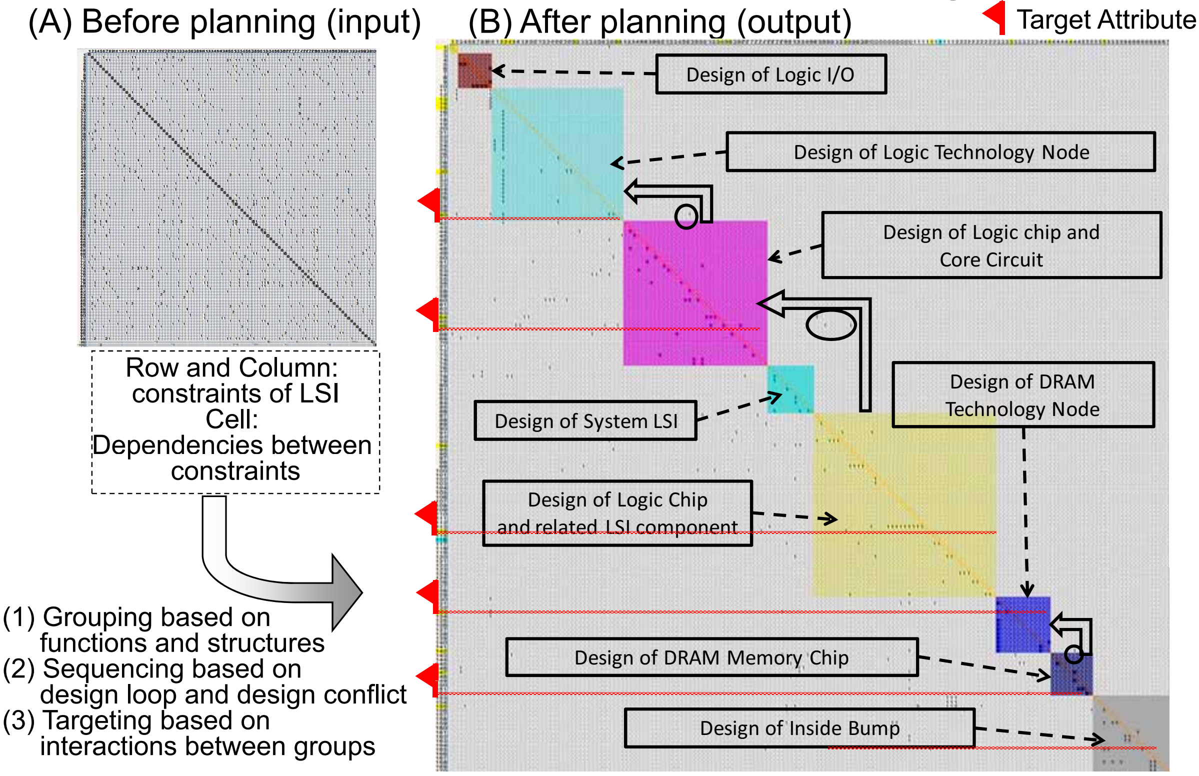
After applying ISM method



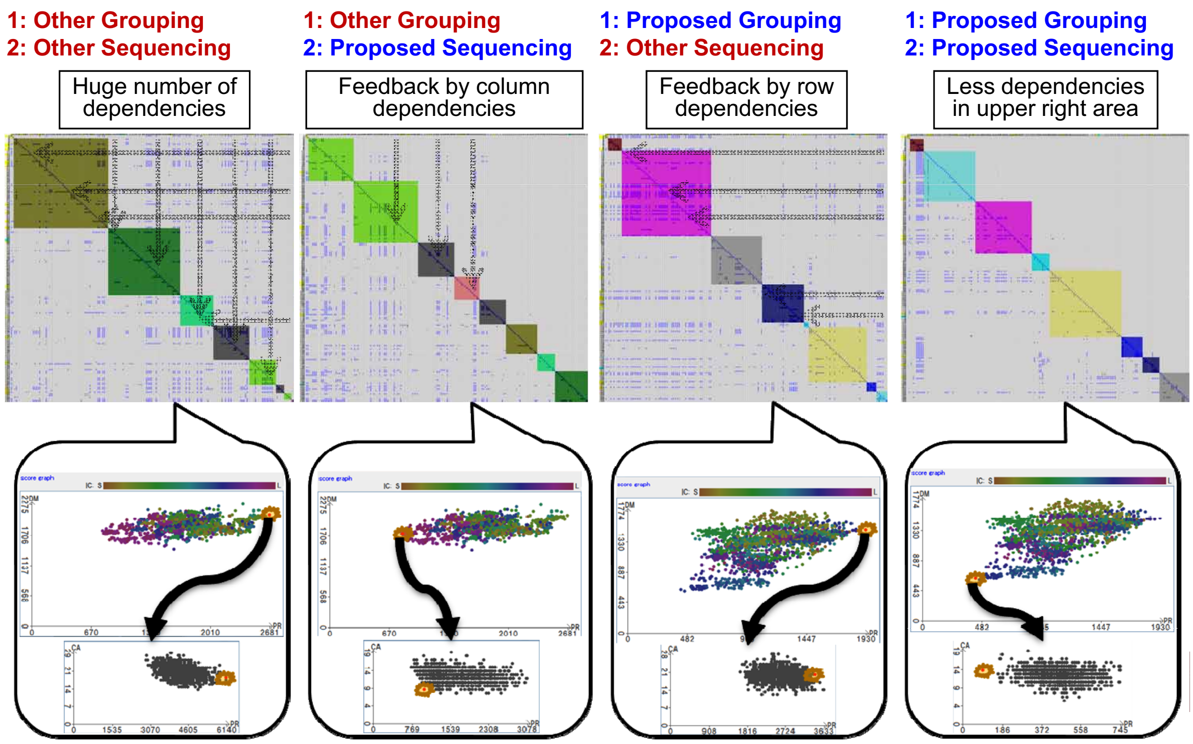
Result: proposed process of LSI design

(A) Before planning (input) (B) After planning (output)



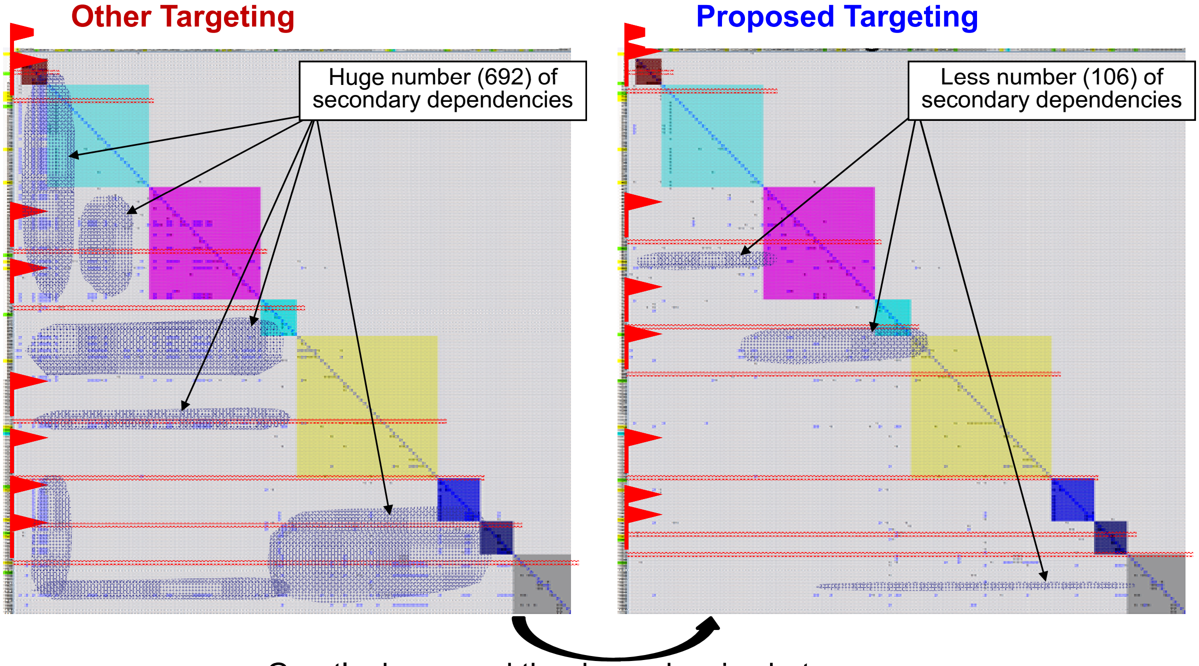
(1) Grouping based on functions and structures
(2) Sequencing based on design loop and design conflict
(3) Targeting based on interactions between groups

Discussion (1) Efficacy of Grouping and (2) Sequencing



Discussion (3) Efficacy of Targeting

Other Targeting | **Proposed Targeting**



Greatly decreased the dependencies between groups
Groups can be designed more independently

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Conclusion and future works

- Process planning method is proposed
  - Grouping considering functions and structures
  - Sequencing to reduce design loop and design conflict
  - Targeting to reduce interactions between groups

- Contribution is confirmed by LSI design
  - Efficacy of grouping: complexity of design process is reduced
    - Number of feedbacks caused by <u>direct dependencies</u> in column line is <u>reduced</u>
  - Efficacy of sequencing:
    - Number of feedbacks caused by <u>direct dependencies</u> in row line is <u>reduced</u>
  - Efficacy of targeting:
    - Complexity of design process is reduced
    - Number of <u>secondary dependencies</u> between groups is <u>reduced</u> from 692 to 106

- Design result indicated that proposed method can contribute to derive good design process