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OPM 781 Seminar Thesis HWS 2021

Product Line Design: Current Heuristic Approaches

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Agenda

1. Seminar Motivation
2. Literature Review
3. Current Algorithms
4. The Model of Tabu Search
5. Implementation of Tabu Search

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1. Seminar Motivation

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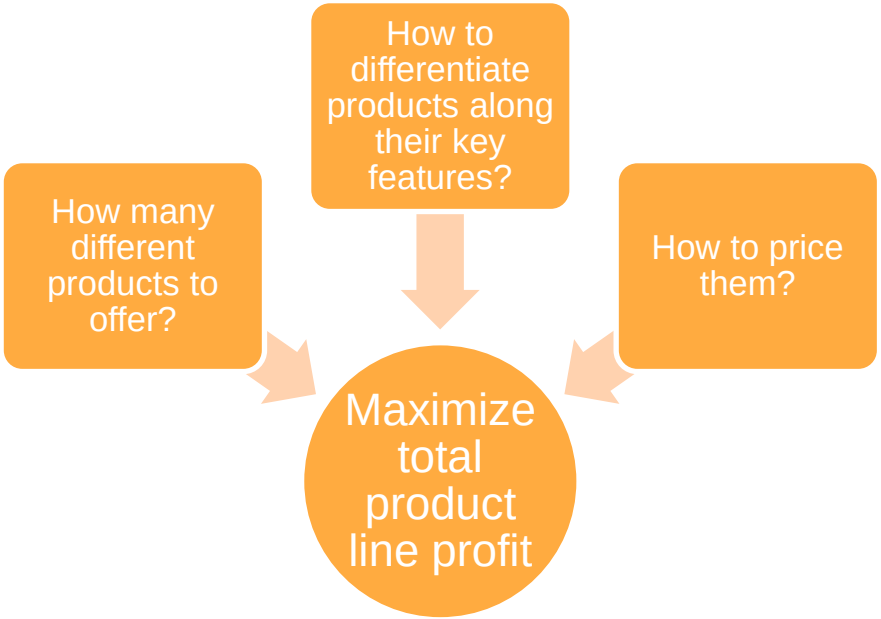
Product Line Design: theory refresh from class

Product Line Design : an attempt to answer **simultaneously** the three questions below so that an objective (i.e., profit or market share) is achieved.

Difficult problem : due to (1) a **large search space** (i.e., NP-complete) and (2) a **multimodal objective function** (i.e., non-convex & non-linear).



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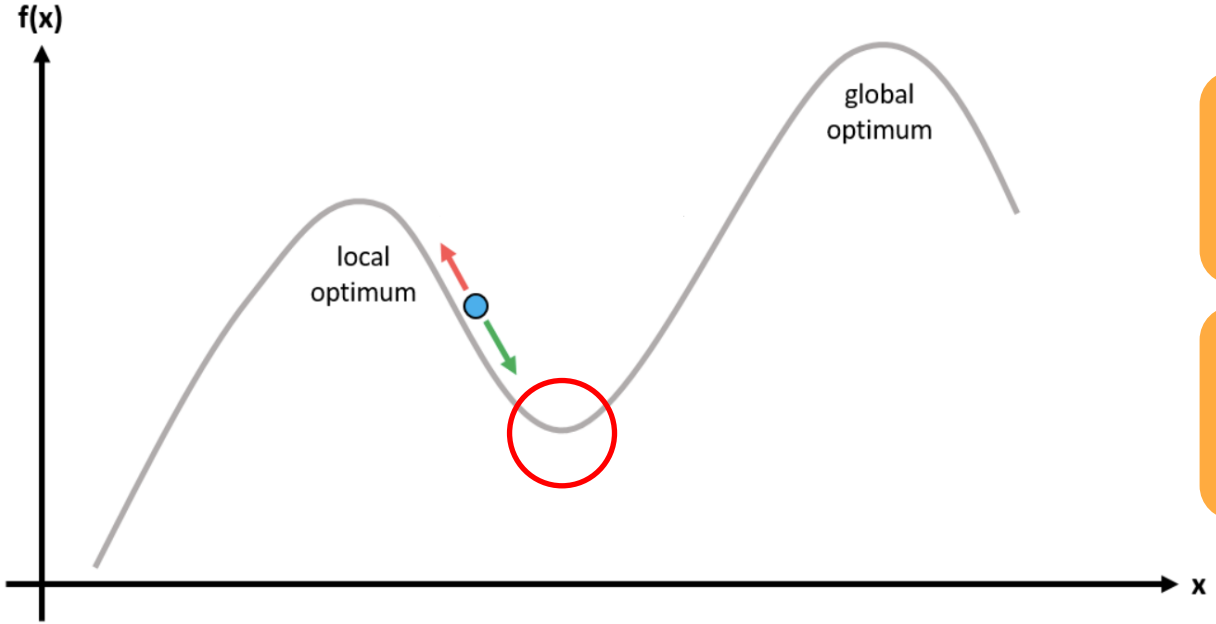
Searching is difficult in multimodal functions



Where is the global optimum ?

How to avoid local minima ?

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We are searching for ways to perform relatively accurate search in economical time

- Managerial implication - **faster** product **launch** and **lower** chance of **product failure**
- **Effective search** approach for the (near) global optimum
- **Improvement** to traditional algorithms

More complex problems with a big volume of data can be accepted

Searching through the solution space is efficiently performed with relatively high accuracy

Higher visibility on profit can be attained and firm competitiveness can be better improved

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2. Literature Review

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Methodology involves the search in various databases

Problem:

Heuristic approaches take root in **different fields**

+

Different databases **required different access**

=> Research papers are **scattered** and might be **unaccessible**

Solution:

Scan the abstract for **relevancy** and **expand** the search into the field of **computer science** and **artificial intelligence** for **background knowledge** in heuristics

Narrow down which of the articles to focus on (i.e., implemented heuristics in PLD)

Recent implementation of 5 modern heuristics enriched the literature on PLD

Traditional ⟵ ⟶ **Modern**

Nair et al.: Near Optimal Solutions for Product Line Design and Selection: Beam Search Heuristics

Tsafarakis et al.: Particle Swarm Optimization for Optimal Product Line Design

Zervoudakis et al.: A New Hybrid Firefly – Genetic Algorithm for the Optimal Product Line Design Problem

Pantourakis et al..: Clonal Selection Algorithms for Optimal Product Line Design: A Comparative Study

Tsafarakis et al.: Optimal product line design using Tabu Search

1995 — 2008 — 2011 — 2013 — 2019 — 2020 — 2021

Belloni et al.: Optimizing Product Line Design: Efficient Methods and Comparisons

Tsafarakis et al.: Hybrid Particle Swarm Optimization with Mutation for Optimizing Industrial Product Line: An Application To A Mixed Solution Space Considering Both Discrete and Continuous Design Variables

Tsafarakis et al.: Fuzzy Self-tuning Differential Evolution for Optimal Product Line Design

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Modern algorithms outperform tradititional algorithms in accuracy and time

Relatively few research papers (i.e., 5)

- Breath over depth
- Similar problem addressed
- Basis for future research

Modern versus traditional heuristics

- General outperformance
- Adaptability to complex problems
- Possibility to combine heuristics

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3. Current Algorithms

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Modern algorithms do have advantages and drawbacks

No.	HEURISTICS	ADVANTAGES	DISADVANTAGES
1	Firefly Algorithm (FA)	-Better performance (*) -Automatic identification of optima -Savings on computational cost	-Subject to parameter settings -Potential subperformance
2	Particle Swarm Optimization (PSO)	-Better performance -High diversity of good solutions	-Subject to parameter settings -Higher requirement for computation power -Potential subperformance
3	Clonal Selection Algorithm (CSA)	-Speed performance	-Subject to parameter settings -Potential subperformance
4	Tabu Search (TS)	-Superior performance on speed and accuracy -Implementation Simplicity	-Subject to parameter settings
5	Differential Evolution (DE)	-Accuracy performance	-Subject to parameter settings

4. The Model of Tabu Search

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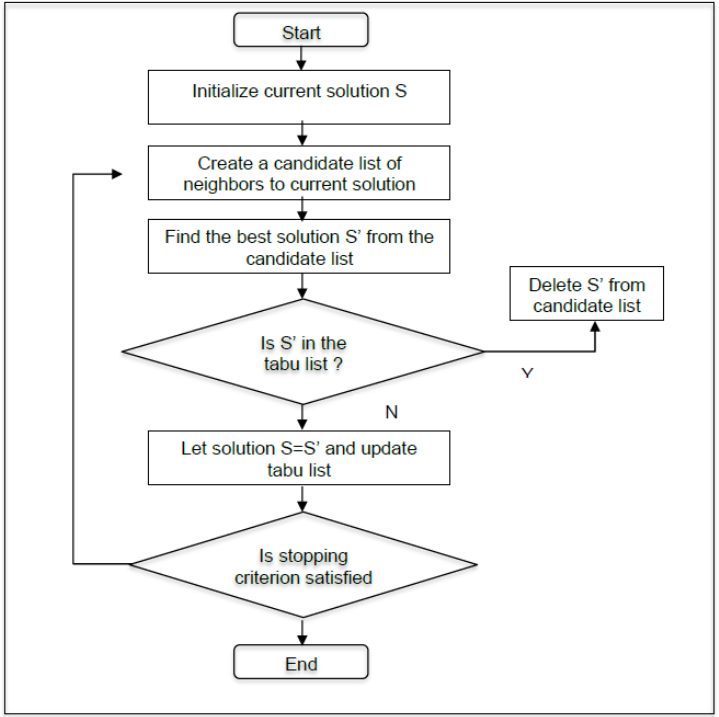
Tabu Search is a simple memory-based algorithm yet is considerably effective

Distinctive feature

- Tabu List
- Certain moves are forbidden
- Allowance for further exploration

Learning possibilities

- Guided path versus random move
- Adaptive tabu list
- Freedom in parameter settings



Source: Hao/Wu/Boriboonsomsin/Barth (2017, p. 486ff)

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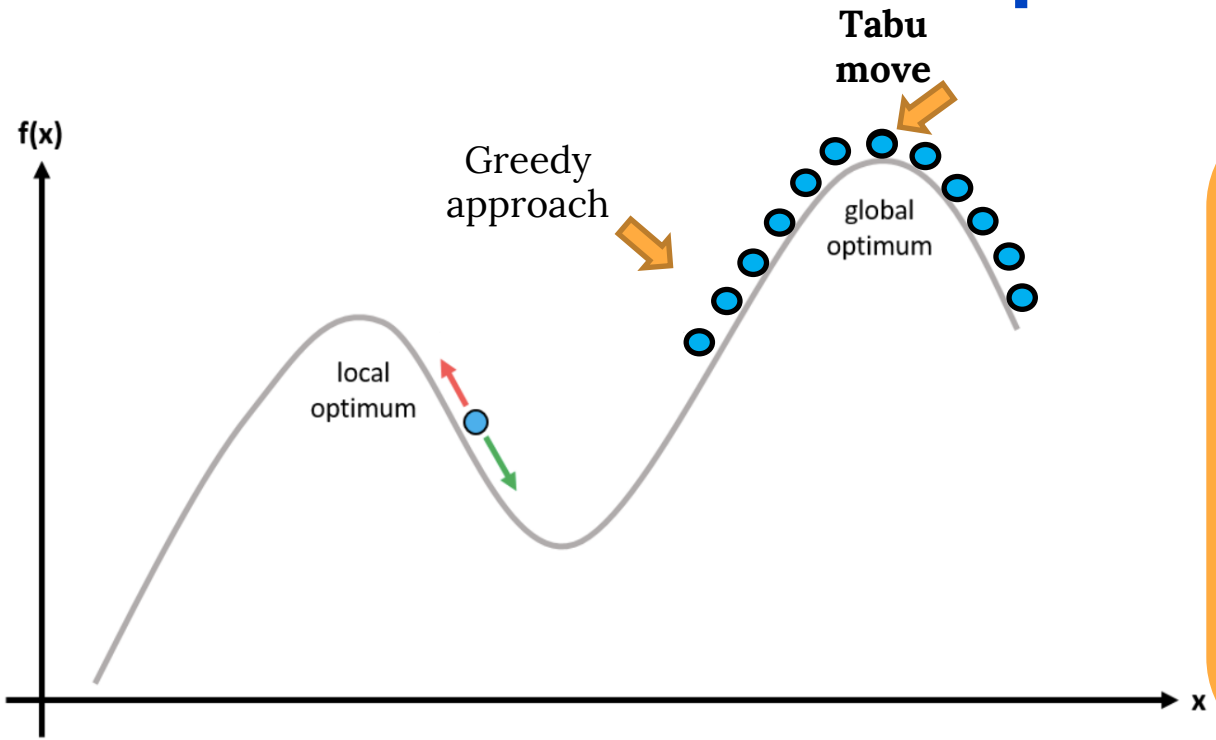
Search occurs in the solution space with ease



Because tabu moves (optima) are memorized, further exploration is allowed. Thus, we can say which optima is the global optimum.

5.
Implementation of Tabu Search

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Tabu Search is implemented to solve…

- The **PLD problem** from OPM 682 lecture on 5 – 14 – 2021
- The optimal **1-product line** instead of 7-product line
- Choice of environment: **Microsoft Excel**
- **Brute force** search for solution **verification**

$$Max. \sum_{i \in I} \sum_{j \in J} \sum_{s \in P_j} \omega_i (p_{js} - c_{ij}) \pi_{ijs} \quad (1)$$

Subject to

$$\pi_{ijs} = \frac{A_{ijs} x_{js}}{C_i + \sum_{n \in J} \sum_{s \in P_j} A_{ins} x_{ins}} (i \in I, j \in J, s \in P_j) \quad (2)$$

$$\sum_{s \in P_j} x_{js} \leq 1 \; (j \in J) \quad (3)$$

$$x_j \in \{0,1\} \left(j \in J, s \in P_j\right) \quad (4)$$

$$\pi_{ijs} \in [0,1] \; (i \in I, j \in J, s \in P_j)$$

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Implementation is a 5-step procedure

SOLUTION GENERATION	GENERATION OF ADJACENT SOLUTIONS	COLLECTION OF THE BEST SOLUTION	REPETITION OF STEP 1 – 3	SOLUTION GATHERING
• **Generate** a **random move** into the solution space	• **Generate** 10 **neighboring solutions** to the randomly generated solution (*).	• **Identify** the **best solution** out of the ten solutions and **put** it in the **tabu list** (*).	• **Repeat** Step 1 to Step 3. The iteration process is **capped** at **10 iterations**.	• **Return** the **highest solution** in all 10 iterations.

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Excel Visualization of Step 1 – 3

	Detachable		Processor			Display Size			Memory			Price				Product	Utilities		Choice Probabilities		Unit	Unit	Profit by Segment		Total	Tabu List
Attribute Group	yes	no	i3	i5	i7	S	M	L	16	32	64	1000	1500	2000	2500	ID	Segment 1	Segment 2	Segment 1	Segment 2	Price	Cost	Segment 1	Segment 2	Profit	Check
Random move:	0	1	1	0	0	0	1	0	0	0	1	0	0	0	1	17478										
1st Search:																										
Detachable	1	0	1	0	0	0	1	0	0	0	1	0	0	0	1	17477	7.5	7	13.04%	6.54%	2500	580	$ 250,435	$ 200,972	$ 451,407	
Processor	0	1	0	1	0	0	1	0	0	0	1	0	0	0	1	17482	8.5	6.4	14.53%	6.02%	2500	480	$ 293,504	$ 194,406	$ 487,910	
Processor	0	1	0	0	1	0	1	0	0	0	1	0	0	0	1	17490	11	7	18.03%	6.54%	2500	580	$ 346,230	$ 200,972	$ 547,201	
Display Size	0	1	1	0	0	1	0	0	0	0	1	0	0	0	1	17446	4.5	2.5	8.26%	2.44%	2500	330	$ 179,174	$ 84,683	$ 263,857	
Display Size	0	1	1	0	0	0	0	1	0	0	1	0	0	0	1	17542	5.3	5	9.58%	4.76%	2500	430	$ 198,391	$ 157,714	$ 356,105	
Memory	0	1	1	0	0	0	1	0	1	0	0	0	0	0	1	16710	2	1.5	3.85%	1.48%	2500	300	$ 84,615	$ 52,020	$ 136,635	
Memory	0	1	1	0	0	0	1	0	0	1	0	0	0	0	1	16966	4	3.5	7.41%	3.38%	2500	340	$ 160,000	$ 116,870	$ 276,870	
Price	0	1	1	0	0	0	1	0	0	0	1	1	0	0	0	3142	10.5	9	17.36%	8.26%	1000	380	$ 107,603	$ 81,908	$ 189,512	
Price	0	1	1	0	0	0	1	0	0	0	1	0	0	1	0	9286	7.5	5	13.04%	4.76%	2000	380	$ 211,304	$ 123,429	$ 334,733	
Price	0	1	1	0	0	0	1	0	0	0	1	0	1	0	0	5190	8.5	7	14.53%	6.54%	1500	380	$ 162,735	$ 117,234	$ 279,969	
Max Profit/ 1st Tabu:	0	1	0	0	1	0	1	0	0	0	1	0	0	0	1	17490									$ 547,201	

- **Unique** neighboring solutions (per attribute)
- **10 searches** per run, **5 runs** in total
- Coverage of **2.1x** the total number of possible product-price alternatives (at worst)
- Coverage of **2.3x** the total number of possible product-price alternatives (at best)

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Excel Visualization of the Tabu List

	Tabu List																
	Detachable		Processor			Display Size			Memory			Price				Product	Product
Tabu No.	yes	no	i3	i5	i7	S	M	L	16	32	64	1000	1500	2000	2500	ID	No.
1	0	1	0	0	1	0	1	0	0	0	1	0	0	0	1	17490	204
2	0	1	0	0	1	0	0	1	0	0	1	0	0	0	1	17554	216
3	0	1	0	1	0	0	0	1	0	0	1	0	0	0	1	17546	180
4	0	1	0	0	1	0	0	1	0	1	0	0	0	0	1	17042	212
5	1	0	0	0	1	0	0	1	1	0	0	0	0	0	1	16785	100
6	0	1	1	0	0	0	0	1	0	0	1	1	0	0	0	3206	141
7	0	1	0	1	0	0	0	1	0	1	0	0	0	0	1	17034	176
8	0	1	0	0	1	1	0	0	0	1	0	0	0	0	1	16946	188
9	1	0	0	1	0	0	0	1	0	0	1	0	0	0	1	17545	72
10	0	1	1	0	0	0	1	0	0	0	1	0	0	0	1	17478	132

- **Control mechanism** of **forbidden** moves
- **10 optima**, including the (near) **global optimum**

Identification of Tabu Moves in Subsequent Searches

	Detachable		Processor			Display Size			Memory			Price				Product	Utilities		Choice Probabilities		Unit	Unit	Profit by Segment		Total	Tabu List
Attribute Group	yes	no	i3	i5	i7	S	M	L	16	32	64	1000	1500	2000	2500	ID	Segment 1	Segment 2	Segment 1	Segment 2	Price	Cost	Segment 1	Segment 2	Profit	Check
Random move:	0	1	0	1	0	0	1	0	0	0	1	0	0	0	1	17482										
8th Search:																										
Detachable	1	0	0	1	0	0	1	0	0	0	1	0	0	0	1	17481	9.5	9.4	15.97%	8.59%	2500	680	$ 290,588	$ 250,208	$ 540,797	⚠ 17481
Processor	0	1	1	0	0	0	1	0	0	0	1	0	0	0	1	17478	6.5	4	11.50%	3.85%	2500	380	$ 243,894	$ 130,462	$ 374,355	No
Processor	0	1	0	0	1	0	1	0	0	0	1	0	0	0	1	17490	11	7	18.03%	6.54%	2500	580	$ 346,230	$ 200,972	$ 547,201	⚠ 17490
Display Size	0	1	0	1	0	1	0	0	0	0	1	0	0	0	1	17450	6.5	4.9	11.50%	4.67%	2500	430	$ 238,142	$ 154,707	$ 392,849	No
Display Size	0	1	0	1	0	0	0	1	0	0	1	0	0	0	1	17546	7.3	7.4	12.74%	6.89%	2500	530	$ 250,977	$ 217,177	$ 468,154	No
Memory	0	1	0	1	0	0	1	0	1	0	0	0	0	0	1	16714	4	3.9	7.41%	3.75%	2500	400	$ 155,556	$ 126,121	$ 281,677	No
Memory	0	1	0	1	0	0	1	0	0	1	0	0	0	0	1	16970	6	5.9	10.71%	5.57%	2500	440	$ 220,714	$ 183,630	$ 404,344	No
Price	0	1	0	1	0	0	1	0	0	0	1	1	0	0	0	3146	12.5	11.4	20.00%	10.23%	1000	480	$ 104,000	$ 85,142	$ 189,142	No
Price	0	1	0	1	0	0	1	0	0	0	1	0	0	1	0	9290	9.5	7.4	15.97%	6.89%	2000	480	$ 242,689	$ 167,568	$ 410,257	No
Price	0	1	0	1	0	0	1	0	0	0	1	0	1	0	0	5194	10.5	9.4	17.36%	8.59%	1500	480	$ 177,025	$ 140,227	$ 317,251	No
Max Profit:																										
8th Tabu:	0	1	0	0	1	0	1	0	0	0	1	0	0	0	1	17490									$ 547,201	

- **Only** check forbidden moves of **previous** searches
- **Limitation** of Excel in generating **unique** random values in **dynamic arrays**

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Impressive results are recorded under Tabu Search

Brute Force Search Optimal Solution	
Product ID:	17489
Profit:	$583,085

	Tabu Search				
	Run 1	Run 2	Run 3	Run 4	Run 5
Average Profit:	$400,398	$470,265	$389,662	$389,662	$399,314
Highest Profit:	$583,085	$583,085	$583,085	$583,085	$528,084
% Highest Profit to Optimal Solution:	100%	100%	100%	100%	91%
Position of Highest Profit Product:	6	7	2	1	7
Product ID of Highest Profit Product:	17489	17489	17489	17489	17554

Appendix C: Result comparison between brute force search and tabu search

- **Global optimal** solution is **identified**
- General **high fitness** to the optimal solution
- Ability to **getting past local minima**

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Implementation is not without drawback

- Implementation of an automatic tabu list checking process was not possible
- Excel can’t link the ever changing values
- Excel does not allow for exclusion of a dynamic array
- Small problem

The End

Thank you for listening!

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The End

Special thanks to Oliver Vetter for valuable guidance and feedback!

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Q&A

Q1 Can we generalize the result from Tabu Search ?

Q2 How much reliable is the result from Tabu Search ?

Q3 What are the applications of Tabu Search?