Agenda

1. Business Background

2. The Strategic Business Problem

3. Mathematical Formulation

4. Our New Solution

5. Our Custom Implementation

6. Growing Business Impact

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Leading Edge Process Technology

Lower Transistor Leakage

65nm   45nm   32nm   22nm*

1x

0.1x

0.01x

0.001x

" … more than 6 million 22nm transistors can fit in the period at the end of this sentence."

* projected

Higher Transistor Performance (Switching Speed)

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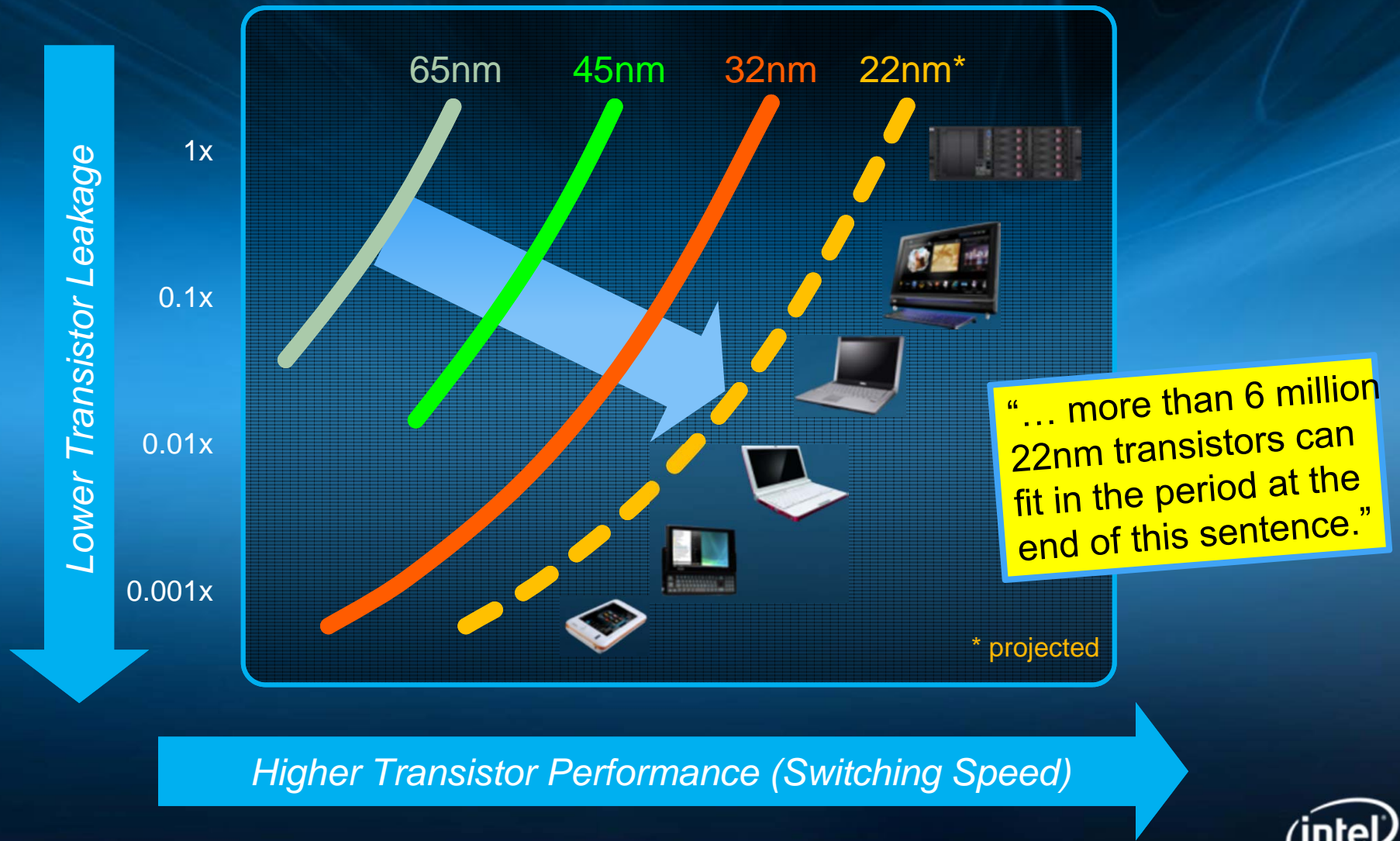
Leading Edge Product Technology

| DATA CENTER | PC CLIENT | ULTRA MOBILITY | EMBEDDED & COMMS | DIGITAL HOME |

- 2 Billion transistors/core
- 4 cores/chip

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5
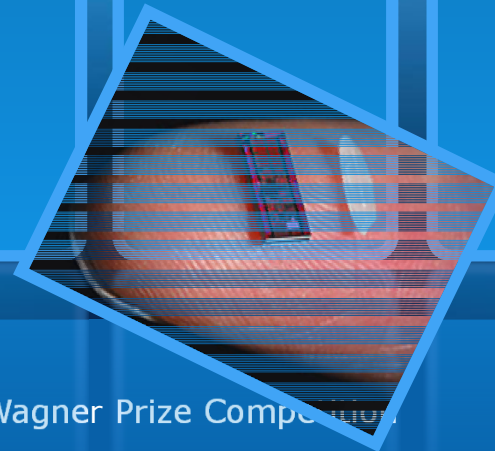
Feature, Market, and Time Dynamics

Different Markets Need a Different Mix of Features

Market1	$13	240,000
Market2	$15	300,000
Market3	$14	450,000
Market4	$12	880,000
Market5	$ 9	900,000
Marketing	**ASP**	**Vol**

Selling the product in the market brings in revenue

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Different Markets Need
a Different Mix of Features

Engineering and manufacturing incurs costs

Feature1	Feature2	Feature3	Feature4	Feature5	Feature6	Eng & Mfg
$ 300,000	$ 400,000	$ 400,000	$ 250,000	$ 300,000	$ 200,000	Eng Cost
$ 1.50	$ 0.35	$ 1.25	$ 0.50	$ 0.50	$ 0.25	Mfg Cost / u

Market1	$13	240,000
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	$ 1.50	$ 0.35	$ 1.25	$ 0.50	$ 0.50	$ 0.25	Mfg Cost / u
Market1	$13	240,000	1	0	0	1	0	1
Market2	$15	300,000	1	0	0	0	1	1
Market3	$14	450,000	1	1	2	0	0	0
Market4	$12	880,000	2	0	1	0	0	0
Market5	$ 9	900,000	1	3	0	0	0	0
Marketing	ASP	Vol						

Markets have unique feature requirements

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Different Markets Have Different Timings
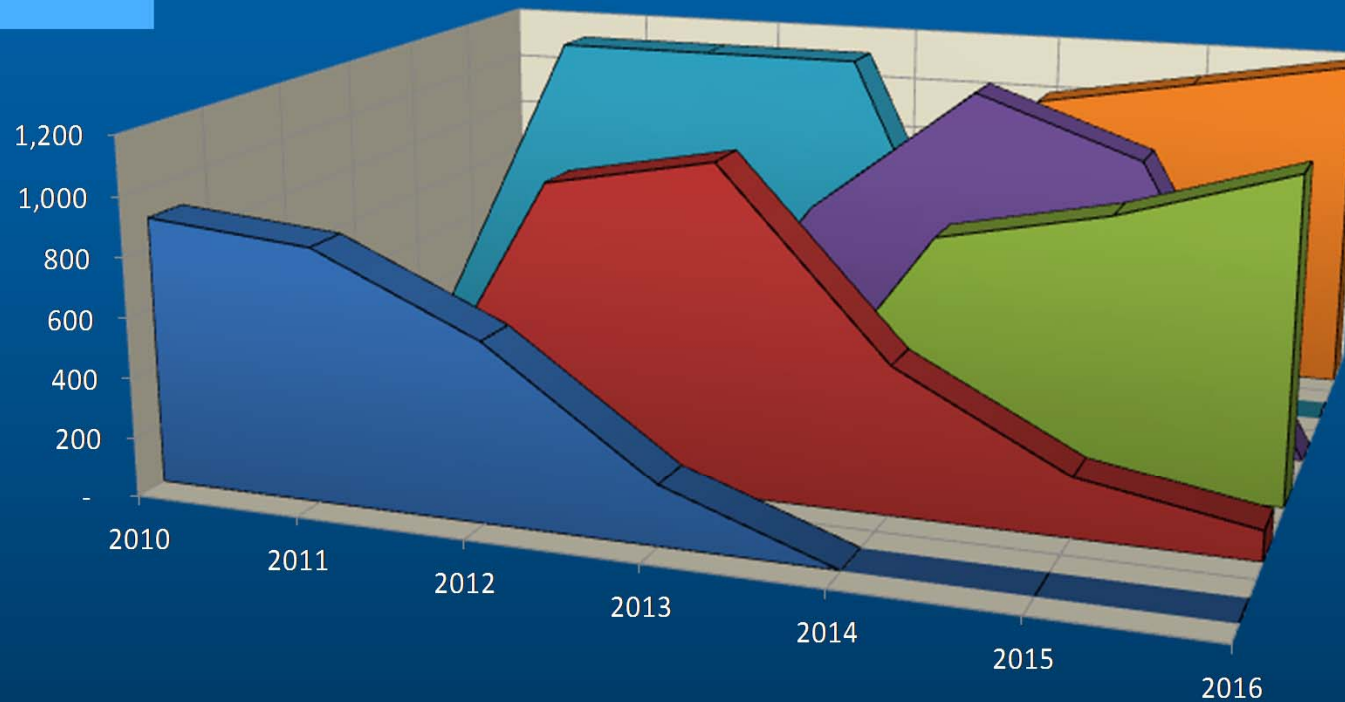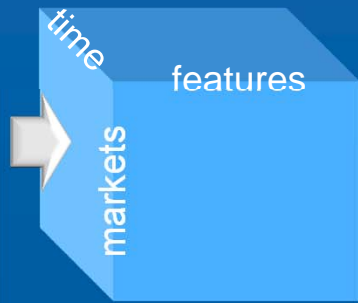
Markets are not all synchronized in time
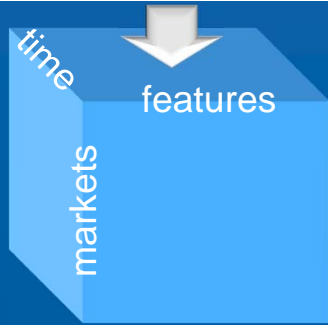
Different Features Have Different Availabilities

features

time

markets

BUILD

BUY

Partial Reuse

REV 2.0

REV 1.0

Feature5

Feature4

Feature3
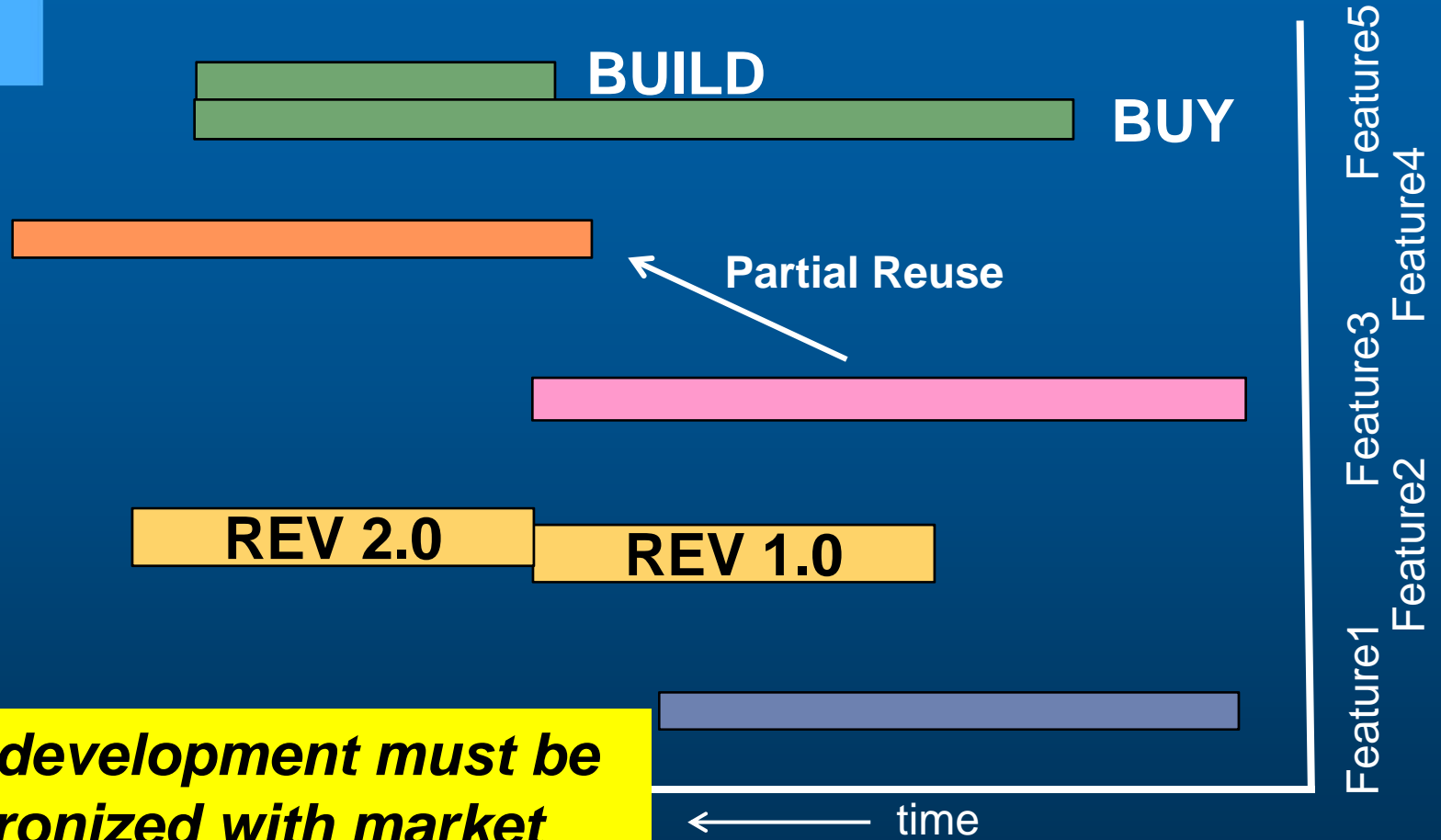
Feature2

Feature1

Feature development must be synchronized with market windows

time

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Constraints

- **Feature sets in the products must meet (or exceed) the needs of the target markets**

- **Features must be engineered in time to be integrated into the products**
- **Products must be engineered and manufactured to hit the market timings**

- **The engineering budget is finite (leading to an emphasis on reuse)**

Objective

- **Maximize Profit** *(Max Revenue, Min Eng and Mfg Cost)*

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Business questions include (at least):

- **Given an engineering budget, what set of products maximize revenue or profit?**

- **Given a revenue target, what set of products minimize cost, with what engineering budget?**

- **Given a number of Features to engineer, what is the profit maximizing order of development?**

- **Given a Feature 'build vs. buy' decision (cost, timing), which generates the most profit?**

Difficult to solve with standard techniques due to many different constraints, competing objectives, and interrelated tradeoffs

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Math

Define Problem & Formulate as Mathematical
Programming

Show Complexity & Difficulties involved with
Traditional techniques

Solution Methodology & Implementation

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The Core Problem

Generate a Product Line   *Strategic*

   Map products into markets

   Schedule product development

Generate Product Features
Tactical

   Meet or exceed market requirements

   Schedule feature development

Optimize for Profitability   *Strategic*

   Product line must optimize profitability

   Must consider engineering budgets

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Generating the Product Line

Inputs

    Set of markets $\{1,...,M\}$

    Number of products *at most one product per market* $P \leq M$

    Time horizon $\{1,...,T_0,...,T\}$

Decisions

    How many products to build β_p *Binary*

    $z_p \in \{T_0,...,T\}$ *Integer*

    When to introduce products α_{pmt} *Binary*

    Which markets to sell products into?

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Generating Product Features

Inputs

Set of features $\{1,...,F\}$

Market Requirements D_{mf}

Decisions

Product Features *Units of Feature f in Product p* x_{pf} *Integer*

Feature Availability $y_f \in \{T_0,...,T\}$ *Integer*

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Optimize for Profitability

Inputs

Market Volumes and Prices

$$v_{mt}, p_{mt}$$

Feature Engineering Cost (with Reuse)

$$R_f(t)$$

Product Engineering Cost

$$A$$

Feature Mfg. Cost

$$c_f$$

Expressions

Revenue

$$\sum_{p=0}^{P} \sum_{m=0}^{M} \sum_{t=0}^{T} \alpha_{pmt} v_{mt} \left(p_{mt} - \sum_{f=0}^{F} c_f x_{pf} \right)$$

Engineering Cost

$$A \sum_{p=0}^{P} \beta_p + \sum_{f=0}^{F} \sum_{t=0}^{T} R_f(t)$$

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Reuse Function

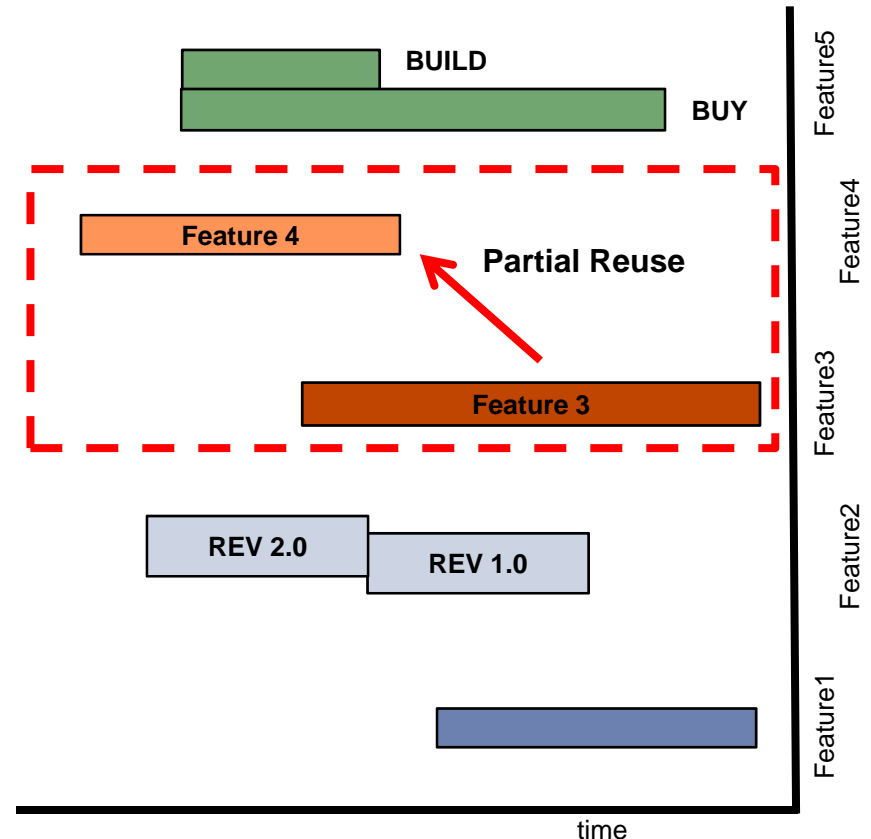Engineering features presents **reuse** opportunities

Developing **Feature 3** <u>may</u> cause developing Feature 4 to be cheaper/faster

The **Reuse Function** defines these reuse synergies

Typically dynamic and complex

BUILD

BUY

Feature 4

Partial Reuse

Feature 3

REV 2.0

REV 1.0

Feature5

Feature4

Feature3

Feature2

Feature1

time

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Reuse Function Example

A hypothetical Reuse Function where developing one feature in a group causes subsequent feature development to be 50% cheaper

Feature f	Group $G(f)$	$R_f(t)$ when $t - 1 = y_f$
1	1	1
2	2	.5 if $y_2 > y_3$, else 1
3	2	.5 if $y_3 > y_2$, else 1
4	3	.5 if $y_4 > y_5$, else 1
5	3	.5 if $y_5 > y_4$, else 1

$$R_f(t) = \begin{cases} 1 \text{ if} & y_f = \min_{g \in G(f)} y_f \\ .5 \text{ if } \exists g \in G(f) \mid y_g < y_f \end{cases}$$

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Full Formulation

Objective: Maximize Profit

$$\max \sum_{p=0}^{P} \sum_{m=0}^{M} \sum_{t=0}^{T} \alpha_{pmt} V_{mt} \left(P_{mt} - \sum_{f=0}^{F} C_f x_{pf} \right) - \sum_{f=0}^{F} \sum_{t=0}^{T} R_f(t) - A \sum_{p=0}^{P} \beta_p$$

Subject to:

$\sum_{p=0}^{P} \alpha_{pmt} \leq 1 \quad \forall m, t$	One Product per Market
$D_{mf} \alpha_{pmt} \leq x_{pf} \quad \forall p, m, t$	Market Satisfaction Constraint
$z_p \geq \max\{f : \beta_p > 0 \mid y_f\}$	Product Availability Constraint
$\alpha_{pmt} = 0 \quad \forall p, m, t < z_p$	Market Coverage Availability Constraint
$MT\beta_p \geq \sum_{m=0}^{M} \sum_{t=0}^{T} \alpha_{pmt}$	Product Selling Requirement
$\sum_{f=0}^{F} R_f(t) \leq S_t$	Resource Constraint
$\beta_p \in \{0,1\}$	Binary Constraint
$\alpha_{pmt} \in \{0,1\}$	Binary Constraint
$x_{pf} \in \{0, \ldots, \max D_{mf}\}$	Integral Units of Features Constraint
$y_f \in \{T_0, \ldots, T + \Pi\}$	Scheduling Window Constraint
$z_p \in \{T_0, \ldots, T + \Pi\}$	Scheduling Window Constraint

Why Is This a Hard Problem?

Non-linearity

    Reuse Function

    Objective Function & Constraints

Integral & Binary Decisions

    Scheduling

    Mapping

Combinatorics & Problem Size

Difficult to solve by traditional techniques!
    Linear/Mixed-Integer Programming
    Constraint Programming

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Our Solution

- Integrate diverse OR techniques
  - Resource-Constrained Job Scheduling
  - Optimal Set Covering
  - Portfolio Optimization
  - Dynamic Programming
- Decompose Problem into Multiple Stages
  - Outer "strategic" Genetic Algorithm
  - Inner "tactical" Heuristics and MIPs
  - Financial Optimization through Genetic Algorithm Fitness

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Decomposition – Product Line Design

Outer Genetic Algorithm

1. Product Release Schedule

2. Product to Market Mappings

Inner Set Covering/Heuristics

3. Product Features
   Ext: Feature Substitutions

4. Feature Schedules

5. Feature Reuse

6. Resource Constraints

7. Financial Objectives

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Decomposition – Generate Product Features

Outer Genetic Algorithm

Inner MIPs and Heuristics

1. Product Release Schedule

Per Product →

2. Product to Market Mappings

3. Product Features
   Ext: Feature Substitutions

4. Feature Schedules

5. Feature Reuse

6. Resource Constraints

← Per Product

7. Financial Objectives

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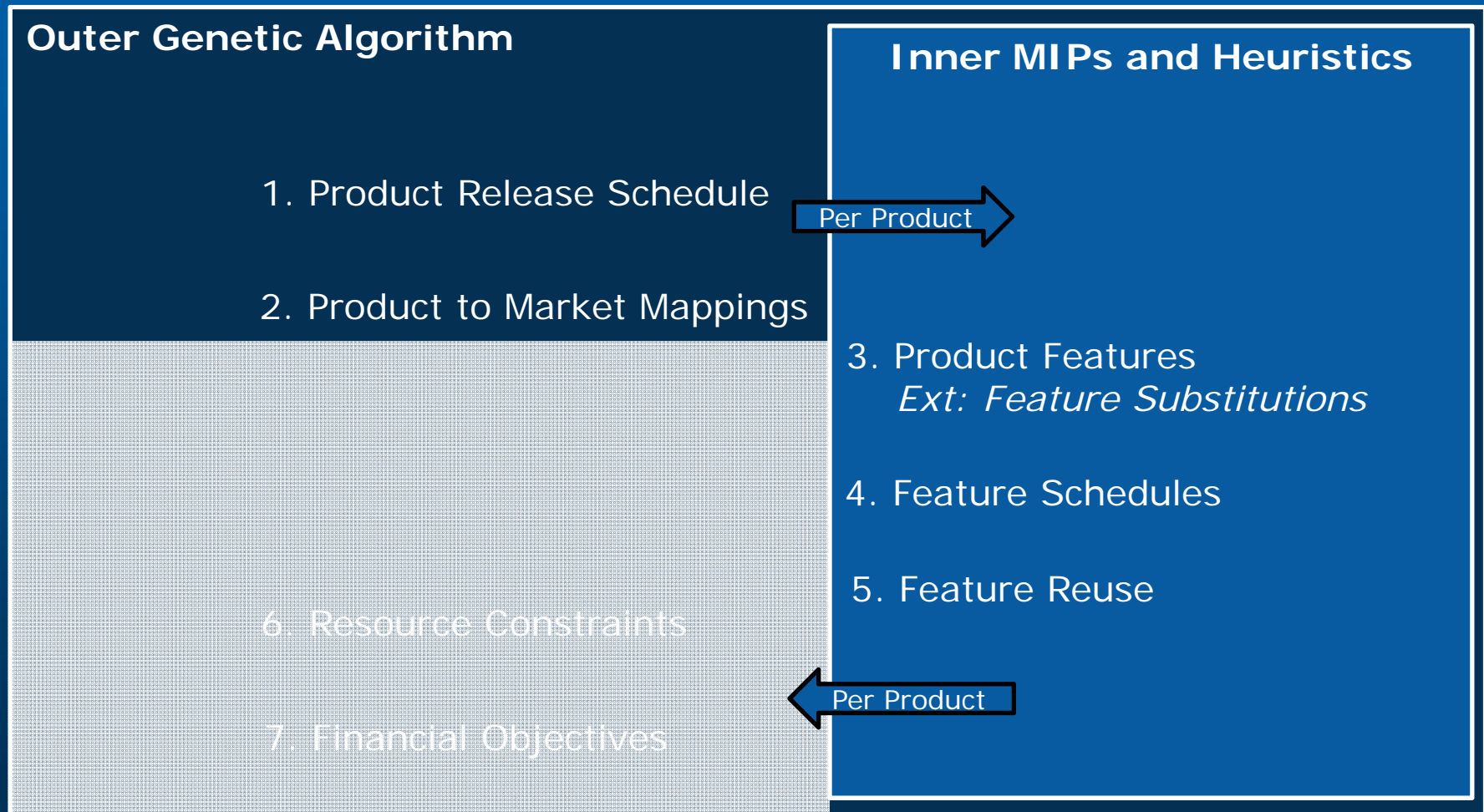
Decomposition – Financial Optimization

Outer Genetic Algorithm

Mutation & Crossover

1. Product Release Schedule

2. Product to Market Mappings

Selection

6. Resource Constraints

7. Financial Objectives

Strategic

Inner Set Covering/Heuristics

Per Product

3. Product Features
   Ext: Feature Substitutions

4. Feature Schedules

5. Feature Reuse

Per Product

Tactica

Outer "Strategic" Algorithm

1. **Outer: Creating Product Schedules**

   Generate a random chronologically sorted product schedule, with some products "turned off".

   Use crossover to "zip" different schedules together and mutations to randomly permute schedule by pushing products out and pulling products in

2. **Outer: Creating Market to Product Mappings**

   For each market randomly cover or skip the market. If covered, select a random product from the list generated in 1

Inner "Tactical" Algorithm

3. **Inner: Determine Product Features (MIPs)**

   - Cover market requirements with minimum manufacturing cost
   - Cover market requirements with minimum engineering cost

   Randomly alternate and allow the evolutionary process to pick the best

4. **Inner: Deduce Feature Schedules**

   Back out the feature engineering schedule based on when the features need to be available for the product's availability (1)

5. **Inner: Evaluate Reuse**

   Evaluate the reuse of the feature schedule from (4)

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Outer "Strategic" Algorithm

6. **Evaluate Resource Constraint**

Evaluate the engineering resources for the entire roadmap

Model engineering resource constraints as soft constraints

Use a Lagrangian penalty approach similar to the concept of an "overtime" cost of exceeding the available engineering resource supply
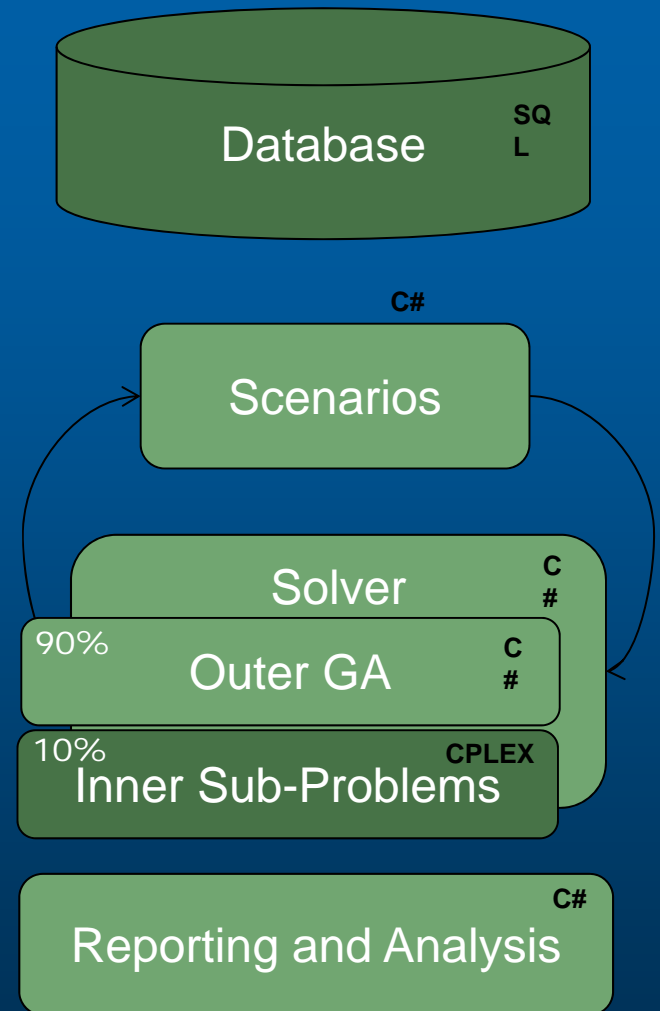
7. **Evaluate NPV & Fitness**

Evaluate the fitness of the product line by determining its NPV and subtracting out any resource overage penalties

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"Pinning" Parts of the Solution

- Planning involves many strategic aspects
  - Not always possible to solve with a "clean slate"
- Solver must be able to "pin" portions of the solution in place and solve using remaining degrees of freedom
- Examples
  - Locking products onto the roadmap
  - Locking feature availability schedules
  - Forcing entry into particular markets

Implementation

- Custom Implementation (C# .NET)
  - Required Custom Mutation/Crossover and Solution Flow
- Inner sub-problem solved via modular heuristics plugged into larger GA
  - Most Heuristics: C#
  - Feature Substitution: OPL CPLEX

Database **SQL**

C#

Scenarios

Solver **C#**

90% Outer GA **C#**

10% Inner Sub-Problems **CPLEX**

Reporting and Analysis **C#**

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The Business Process

BEFORE

1) Many spreadsheets with local databases

2) Local view by product, sometimes by division

3) Few what-ifs

AFTER

1) One tool with global database (HW and SW)

2) Holistic view across divisions and products
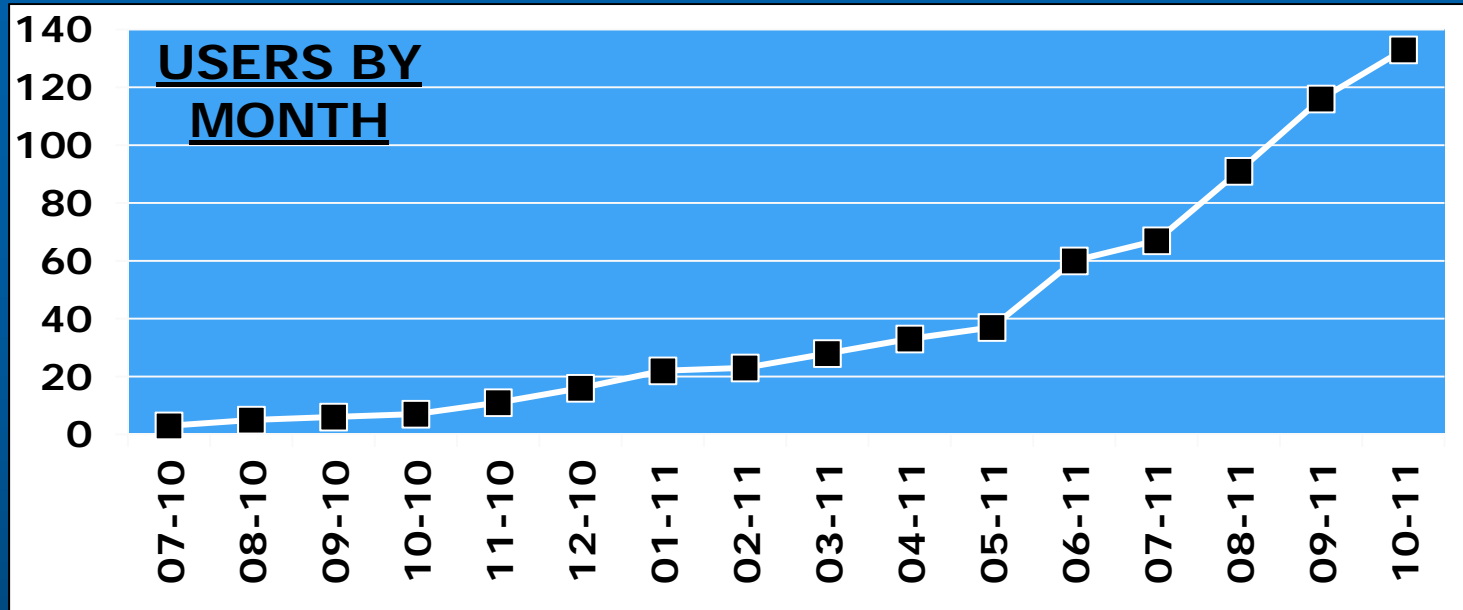
3) Many what-ifs

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The Business Process

BEFORE

1) Many spreadsheets with local databases

2) Local view by product, sometimes by division

3) Few what-ifs

4) Difficult decision making between finance, planning, and engineering (design and mfg)

5) No global optimization and little (if any) local optimization
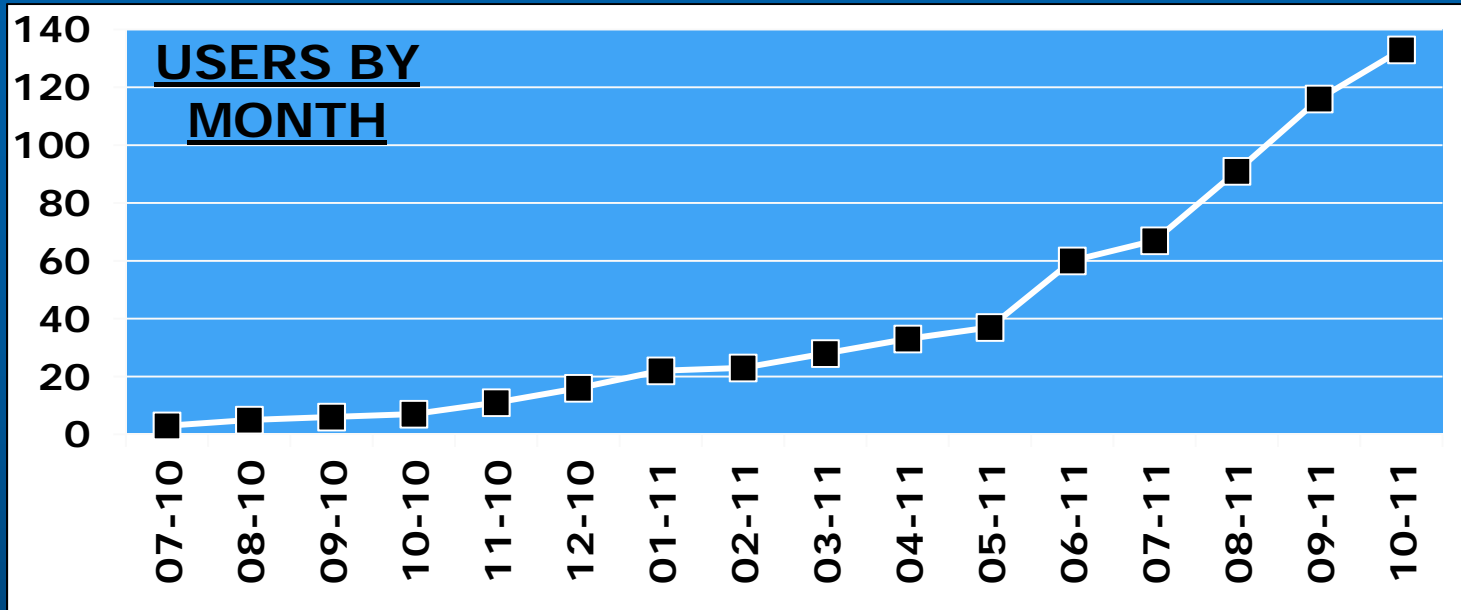
6) Little reuse between divisions and within divisions

AFTER

1) One tool with global database (HW and SW)

2) Holistic view across divisions and products

3) Many what-ifs

4) Collaborative decision making between all of the product functions

5) Global profit optimization

6) Increasing reuse across divs and products (few%/mo)

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User Data and Feedback

USERS BY MONTH

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User Data and Feedback

USERS BY MONTH

JOB TITLE	# USERS	HRS USED
STRATEGIC PLANNERS	16	996
PROJECT/PROGRAM MANAGER	39	476
PRODUCT DESIGN ENGINEER	23	394
FINANCIAL ANALYST	39	342
PRODUCT MARKETING ENGINEER	5	63
OPERATION MANAGER	3	21
PRODUCT SOFTWARE ENGINEER	8	4
TOTAL	133	2296

PRODUCT DIVISION	# OF USERS
Div-1	58
Div-2	25
Div-3	12
Div-4	11
Div-5	9
Div-6	4
Div-7	3
Div-8	3
Div-9	2
Div-Admin	3
Misc	3
TOTAL	133

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User Data and Feedback

USERS BY MONTH

(Line chart showing users growing from ~3 in 07-10 to ~133 in 10-11, with y-axis 0–140 and x-axis months 07-10 through 10-11)

"No idea how we can optimize market coverage without a tool like this."

"We are finally working in a transparent system instead of spreadsheets on random shared drives."

"Useful as an acumen tool as well as learning about where synergies exist for our products."

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Conclusion

- This is a complex problem considering market, feature, and product time dynamics
- Extremely difficult to solve with traditional techniques
- Developed and implemented a custom solution to the problem
- The system currently has users across divisions and job roles
- We believe the system (over time) will become crucial to Intel's continuing success

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Extensions

- Feature Substitution
  - Feature A or Feature B can be interchanged
- Time to Market Penalties
  - Late products suffer in the marketplace
- Minimum vs. Target Market Requirements
  - Feature A is a must-have, Feature B is a value-add
- Build vs. Buy decisions
  - Develop in house or license?
- NPV Optimization