CLEMSON UNIVERSITY’S TACOM/ARC PROJECTS

GEORGES FADEL
MECHANICAL ENGINEERING
PROJECTS

❖ COMPUTER SCIENCE

– CORBA METRICS MODULE
  ◆ Drs. McGregor, Malloy

– PROBLEM SOLVING ENVIRONMENT
  ◆ Drs. Stevenson, Jacobs

– SOLDIER SCANNING MODULE
  ◆ Dr. Pargas

– VIRTUAL ENVIRONMENT MODULE
  ◆ Dr. Geist
PROJECTS (cont.)

❖ MECHANICAL ENGINEERING

– COMPONENT CONFIGURATION
  ◆ Dr. Georges Fadel

– CONCEPT GENERATOR MODULE
  ◆ Dr. Wei Chen
ONGOING PROJECTS

❖ Investigate Multiobjective Optimization Approaches to Vehicle Suspension Design
❖ Develop Rubberband Optimization Algorithm to Facilitate Packing
Configuration Design Optimization Method

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Based on the work of:
Pierre Grignon, Jinhua Huang, Oliver König, Yusheng Li
Real Configuration Design Problems
Initial Goal

• Car Engine and Aerospace Components CDPs.
  – Center of Gravity
  – Volume
  – Maintainability
  – Cooling
  – Vibrations
  – Electromagnetic interference
  – Connectivity
  – ...

Introduction
Configuration Design Context

Part Design
- Shape design
- Materials
- Connectors choice
- Configuration choice

System Design

Introduction

1. Understanding
   Specification Development
   Logistics

2. Conceptual Design

3. Product Design

Design
CDP Initial Basis

• Several Freeform Components
• Functional Connections

• Assembly
  – Thousands of Variables
  – Hundreds of Constraints

• Constraint Satisfaction Problem
CDPs As Multi Objective Optimization Problems

- Add Multiple Objectives

- Constrained Multi-criteria Optimization problem involving non-linear constraints and objectives.
Multi Objective Optimization

Problem Formulation

- \( F : x \rightarrow \{f1 [x], f2[x], f3 [x]\} \ x = \{ x_i \} i = 1 .. n \)
- \( H_k : x \rightarrow H_k[x] = 0 \) (Functional Links -> Geometric Constraints)
  \( - x_{li} \leq x_i \leq x_{ui} \) for \( 1 \leq i \leq n \)

- Find Several \( a \) such that
  - \( F[a] \) is non-inferior
  - and \( H_k[a] = 0 \); for all ‘k’
Multi Objective optimization and Optimal Solutions

- Non-Inferiority

Objective Space

Formulation
CDPs Status

- Non Linear (Discrete/Continuous) Objective Functions - Break Hierarchy
- Linear and Non Linear Equality Constraints
- Thousands of Variables
- Several Solutions
CDPs Simplifications Assumptions

- Too Many Variables
- Too Many Constraints
- Objectives Break Hierarchy
- Non Linear Objectives
- Several Solutions

- Parts are defined
- Variables = Authorized relative and absolute motion between components
- Selected Components

Generalized Packing Problem

Formulation
Genetic Algorithms Principles

**Coding:**

**Individuals:**

\[ X(x_1, x_2) \rightarrow \]

\[ \begin{array}{c}
  x_1 \\
  10101000101110
  \\
  x_2 \\
  11101010101110
\end{array} \]

**Selection**
- Two parents are selected according to their fitness.

**Reproduction**
- The two parents are mated and "give birth" to two children.

**Mutation**
- The genomes of the children have a chance to be randomly altered in order to introduce diversity.

**Replication process: Crossover**

<table>
<thead>
<tr>
<th>Parents</th>
</tr>
</thead>
<tbody>
<tr>
<td>genome parent 1</td>
</tr>
<tr>
<td>genome parent 2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Children</th>
</tr>
</thead>
<tbody>
<tr>
<td>genome child 1</td>
</tr>
<tr>
<td>genome child 2</td>
</tr>
</tbody>
</table>
Handling Non-linearity and Multiple solutions

- Pareto Genetic Algorithms.

  - Select solutions based on ranking
  - Problem requiring niching to diversify the solution
  - Requires additional coding
Handling Non-linearity and Multiple solutions

- Sets based Population with a Genetic Algorithm.

\[
\sum_i \text{Rank ( } P_i [ f_1[x_i], f_2[x_i], f_3[x_i] ] ) / (N+M)^2
\]
## Method Status

<table>
<thead>
<tr>
<th>Number of Variables</th>
<th>Reduced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equality Constraints</td>
<td>Constant shapes</td>
</tr>
<tr>
<td>Non Linear Objectives</td>
<td>Selected Components</td>
</tr>
<tr>
<td>Multiple Solutions</td>
<td>Relative Motion</td>
</tr>
<tr>
<td></td>
<td>GA</td>
</tr>
<tr>
<td></td>
<td>Set based GA Populations</td>
</tr>
</tbody>
</table>

### Reduced
- Constant shapes
- Selected Components
Unconstrained Non-Linear Multi Objective Optimization Problem

- Interference between components
  - \( G_j : x \rightarrow G_j[x] < 0 \) for \( j = 1..N \) (Number of Components)

- Penalty Functions: \( Pty = f(G_j[x]) \)

\[
\sum_{i=1}^{N} \text{Rank} \left( P_i[f_1[x_i], f_2[x_i], f_3[x_i]] \right) / (N+M)^2
\]

\[
\sum_{i=1}^{N} \text{Rank} \left( P_i[f_1[x_i] - Pty, f_2[x_i] - Pty, f_3[x_i] - Pty] \right) / (N+M)^2
\]

Many Local Optima
Configuration Optimization
Design Method Definition

Start

Encode each variable according to its bounds $[L_i, U_i]$  

Generate First Population of Clouds Randomly.

Conventional GA Part

Calculate Clouds Fitness

Evolve 1 Generation

Maximum number of generation or convergence reached?  

yes

End  

no

yes

Final Run?  

Update the variables bounds $[L_i]$
Complexity Classification

GS : Global Search.
LS : Local Search.
GS + LS : Global and Local Search Combined.
Three Criteria Characterizing the Pareto set

- Distances from the extreme planes.
- Point Spreading.
- Flatness.
Test Cases

- Cubes

- Engineering Applications
  - Satellite
  - Car Engine
Results

Tests
Car Engine CDP Description
Car Engine CDP Results

Tests
Achievements

• Configuration Design Optimization Method
  + Provides Multiple Optimal Solutions
  + No Assumptions on Objectives
  + Any type of System (Free form)
  + Respects Constraints
  + Easy Collaboration with the Engineer

• Complexity Classification
  + Gives accurate predictions
Drawbacks

- Small Number of Variables
- Complexity Classification based on Approximation
- Complexity Applied to Each Objective Alone
Future Work

• No Clear Correspondence between Complexity Classifications
• Add Rotations
• More Realistic Solids and Assemblies
• Better Architecture of the Code
Extensions of the Research

- Approximations of the Pareto Set
- Multi-Material Optimization
- Vehicle Dynamics
- Others...
Modeling of Heterogeneous Objects

– HD - Modeling of Heterogeneous Objects Consisting of a Finite Number of Distinct Materials

Product space: \( T = R^3 \times I \) including material dimension
Specific point: \([x, m(x)]\) with material type \(m(x)\)

– HC - Heterogeneous Objects Consisting of two or more primary materials with Continuous Material Variation

Product space: \( T = R^3 \times R^n \) with \(n\) primary materials
Specific point: \([x, v(x)]\) with material fraction vector \(v(x)\)
Heterogeneous Flywheel Design

Jinhua Huang

Optimal HD Profile - Cell-Based Weighting Method \( (f_1 = f_2 = 0.5) \)

Optimal HD Volume Fraction Distribution for Cobalt - Cell-Based Weighting Method \( (f_i = 0.5) \)
Heterogeneous Flywheel Design

Optimal HC Profile - Basis-Function-Based Weighting Method ($f_i = 0.5$)

Optimal HC Volume Fraction Distribution for Cobalt - Basis-Function-Based Weighting Method ($f_i = 0.5$)
Heterogeneous Flywheel Design

Pareto Curve of Normalized Optimal Energy and Difference between Max and Min Von-Mises Stresses for Multi-Objective HD Optimization Design with Weighting Method for $f_1$ Varying from 0 to 1

Minimal optimal energy = 300 kJ
Maximal optimal energy = 571 kJ
Min difference between max and min Mises stresses = 34.0 MPa
Max difference between max and min Mises stresses = 67.6 MPa
Application 3. Turbine Blade

- Mesh: 951 Elements

- Materials
  - Typical Titanium Alloy
  - Silicon Nitride

- Boundary Conditions
  - Boundary Temperatures
  - No Convection & Radiation

- Fitness function

\[
(score = \frac{score_{norm}}{\sum_{i=1}^{N_{ele}} (T_i - T_{work(mat)})^2})
\]

with

\[
T_{work(Ti)} = 1000
\]

\[
T_{work(SiNi)} = 1200
\]
Turbine Blade: Outlook

Problem: Thermal Stresses

Thermal expansion coefficients

\[ \alpha_{Ti} = 10 \frac{\mu m}{m \cdot K} \]
\[ \alpha_{Ce} = 3.3 \frac{\mu m}{m \cdot K} \]

Solution Approaches

1: Minimize thermal stresses

\[ \text{score} = \frac{\text{score}_{\text{norm}}}{\sum_{i=1}^{N_{\text{ele}}} (\sigma_{th(i)} - \sigma_{ref})^2} \]

Subject to:

\[ \max(T_{Ti(i)}) < T_{\text{work} \_ Ti} \]
\[ \min(T_{Ce(i)}) > T_{\text{work} \_ Ti} \]

2: Two-objective optimization

3: Material modeling with HC
Closure

• Optimization as a Design tool can be applied to complex problems such as configuration design or multi-material optimization

• Multi-objective approaches are needed to obtain Pareto Optimal Solutions

• Application to multi-material manufacturing is a novel and challenging research area
Generating animated sequences from 3D wholebody scans

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http://www.cs.clemson.edu/~pargas/animation
Objective

To generate animated sequences from a single 3D scan

Process

• Subdivide human image into segments
• Map the segments to those of a human model
• Use human-motion simulation package
• Capture snapshots of the movement
• Assemble snapshots to create animated sequence
Three views of original image
Uncapped leg and arm segments
Capped arm and leg segments
Animated sequences using segments

Original 3D image

Postures

Animations
Free-form deformation

Objectives

• Provide continuous and smooth movement
• Avoid discontinuities at segment ends (shoulders, knees)
• Finer control over body movement
Free-form deformation

- Create lattice structure around image
- Map image points to lattice points
Animated sequences using free-form deformation

Arm and torso movement:
10 frames/second

(Click on image)
Applications

Visualization tool for simulation of activities involving humans

• Vehicle crash simulations  
  *Information about the forces within the vehicle that may affect human passengers to predict severity of injuries.*

• AI simulations of autonomous human behavior  
  *Independent AI routines may generate actions and movements to be performed by simulated humans, and then transmit the actions to a visualization tool which displays the individual and independent human motions.*