GPU Accelerated Process Planning For CNC-Machined Parts: Industrial Components to Bone Implants

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Introduction

For manufacturing a part using conventional 3-Axis CNC machining process, one must determine a set of machining orientations. Generally this process planning task is carried out manually by the machinist, considering decision parameters such as part visibility, machinability, machining depths, tool geometry, etc. In this work, we modelled this as a Linear optimization problem; the solution to which is a set of machining orientations. The solution methodology employs a Greedy algorithm and a Heuristic Simulated Annealing (SA) approach in order to get a globally optimal solution set of machining orientations. The algorithms yielding process planning parameters (% Visibility and Machinability) are ported on a GPU(Tesla-C2075) [1][2] . The input to these algorithms is a set of 2D slices created from polyhedral .STL files. The software implementation is done in Visual Studio 2010 using C++ and CUDA C.

Objective

The objective of this work is to provide automated process planning for advanced manufacturing systems, specific to this, to determine an optimal set of orientations to create a part using CNC machining.

Objective Function (*Obj F*) & Variables

$$Min\ (f(\Theta_0,\Theta_1,..,\Theta_n)) = \sum_{d=0}^{10}(\emptyset(D)_d) + \alpha(\%\ NV)$$

$$+\beta(\%NM) + \gamma(\%R) + \delta(Theta_{count})$$

$$Min\ \{\emptyset(D)_d\} = \{{}^{V_i}/_{V_{total}} + Min\{\varphi(TD)_d\} + \lambda(TL)_d\}$$

$$Min\ \{\varphi(TD)_d\} = \{({}^{M_i}/_{V_i})_d / TD_d\}$$

d : Machining depth (inch) ($d \in N \mid 0 \le d \le 10$)

Θ_i : Candidate setup orientation ($i \in N \mid 0 \le i < 360$)

% NV : % Non-Visibility of model

% NM : % Non-Machinability of model with Tool Diameter (TD)

% R : % Redundant machined area, from an orientation set

$(M_i)_d$: % Machinability from a Θ_i within a given d

$(V_i)_d$: % Visibility from a Θ_i within a given d

V_{total} : Total Part Visible perimeter

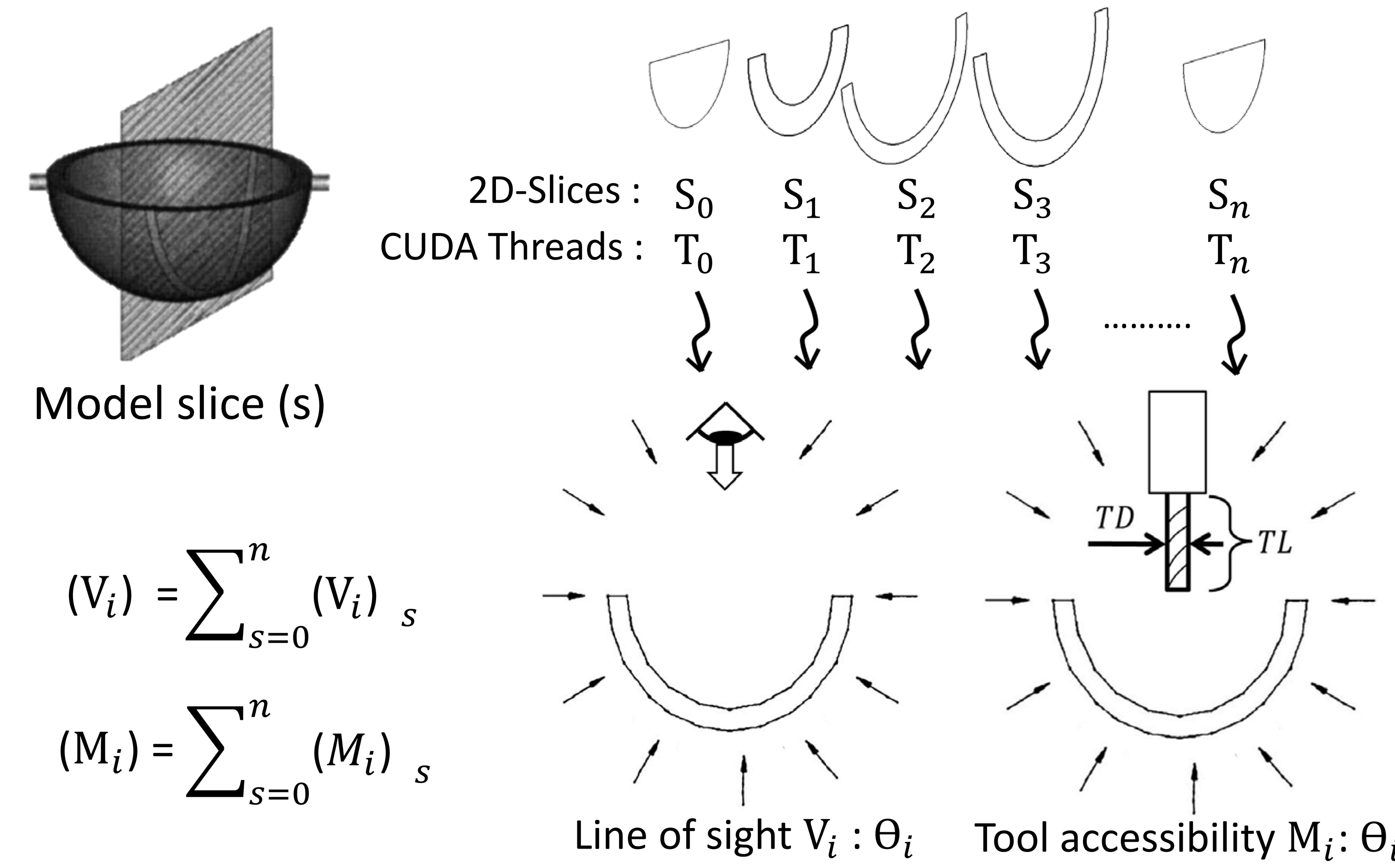
$(TD)_d$: Tool Diameter (inch) used within a given d

$(TL)_d$: Tool Length (inch) used within a given d

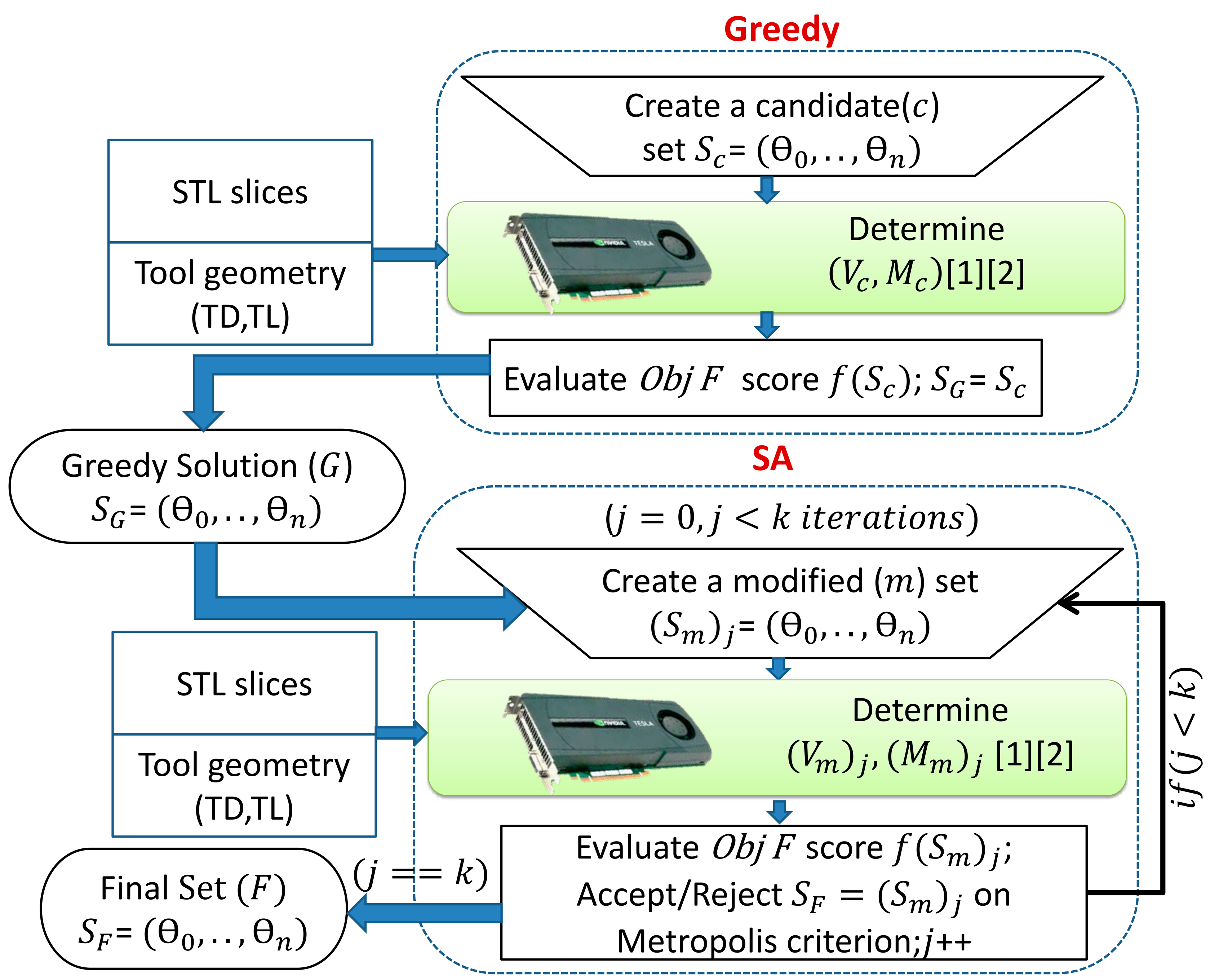
$Theta_{count}$: Setup orientation count in a candidate set

$\alpha, \beta, \gamma, \delta, \lambda$: Penalty Parameters

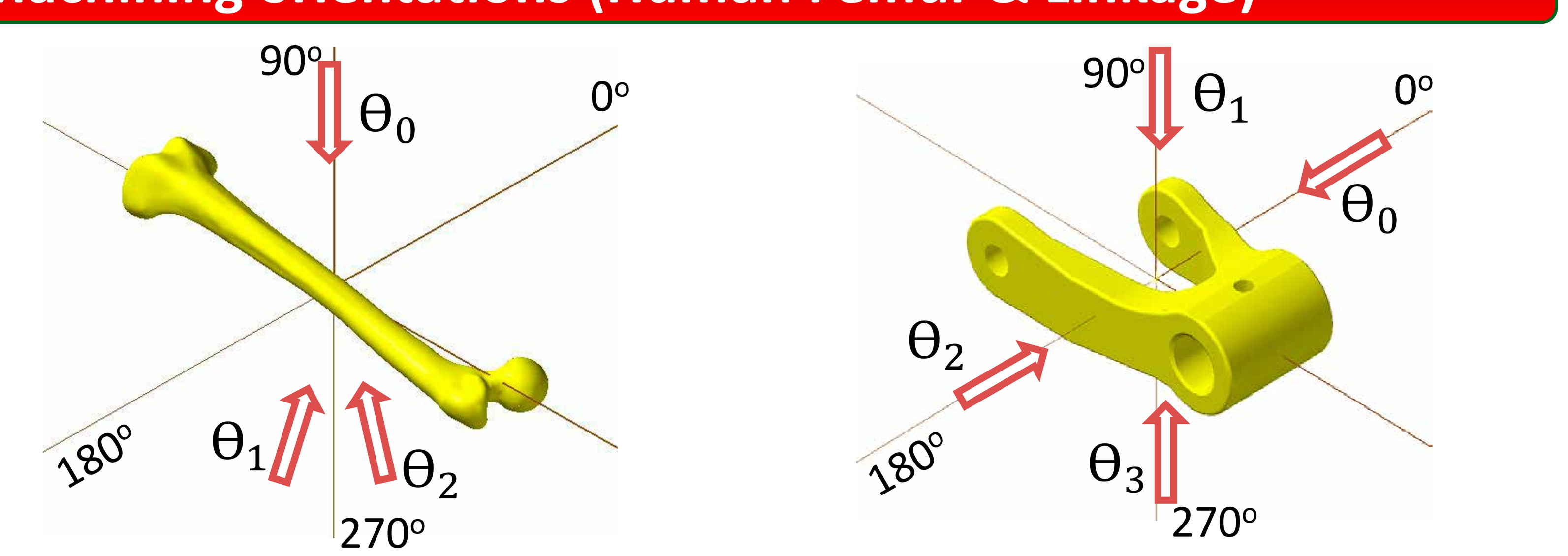
GPU acceleration: Visibility (n^2)/Machinability (n^2)



Solution Methodology (Greedy + SA)

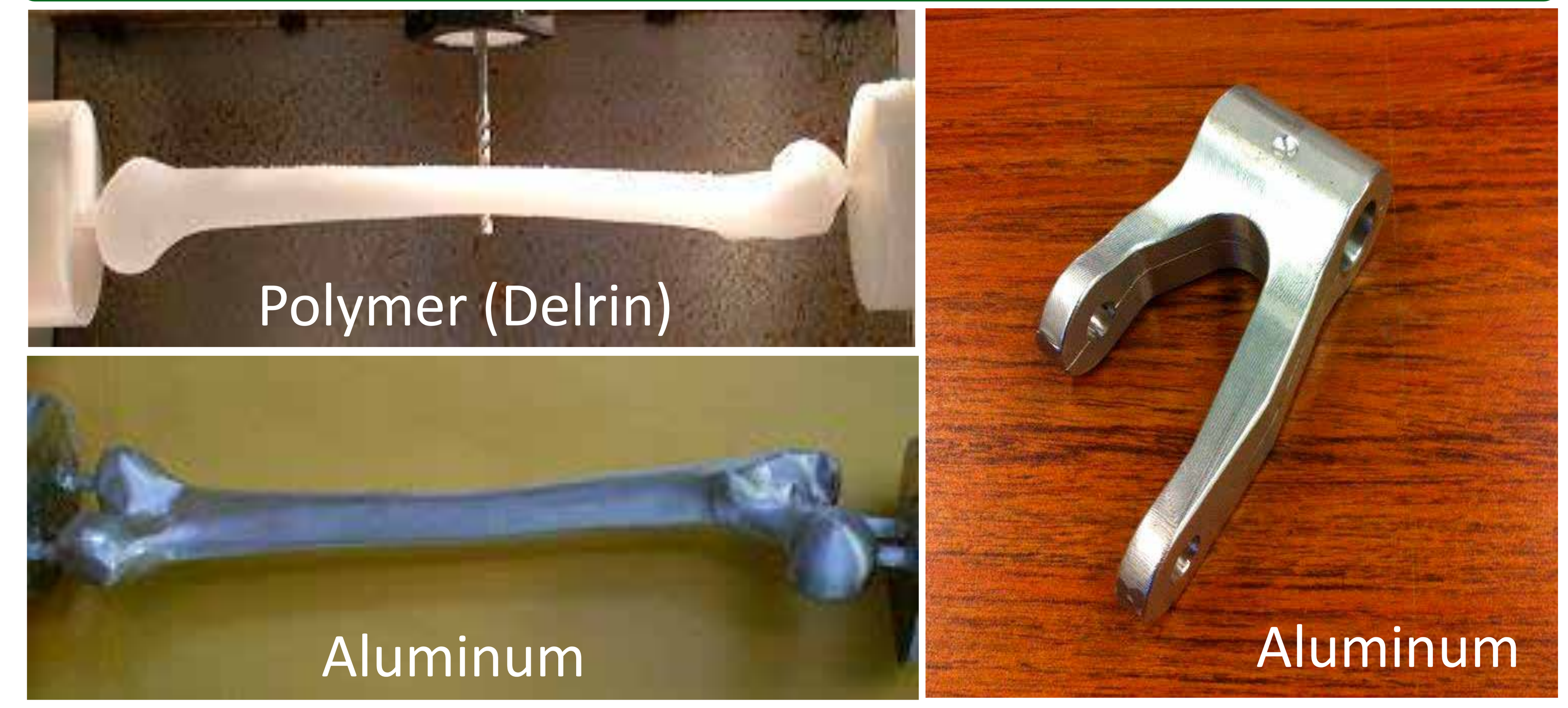


Machining orientations (Human Femur & Linkage)



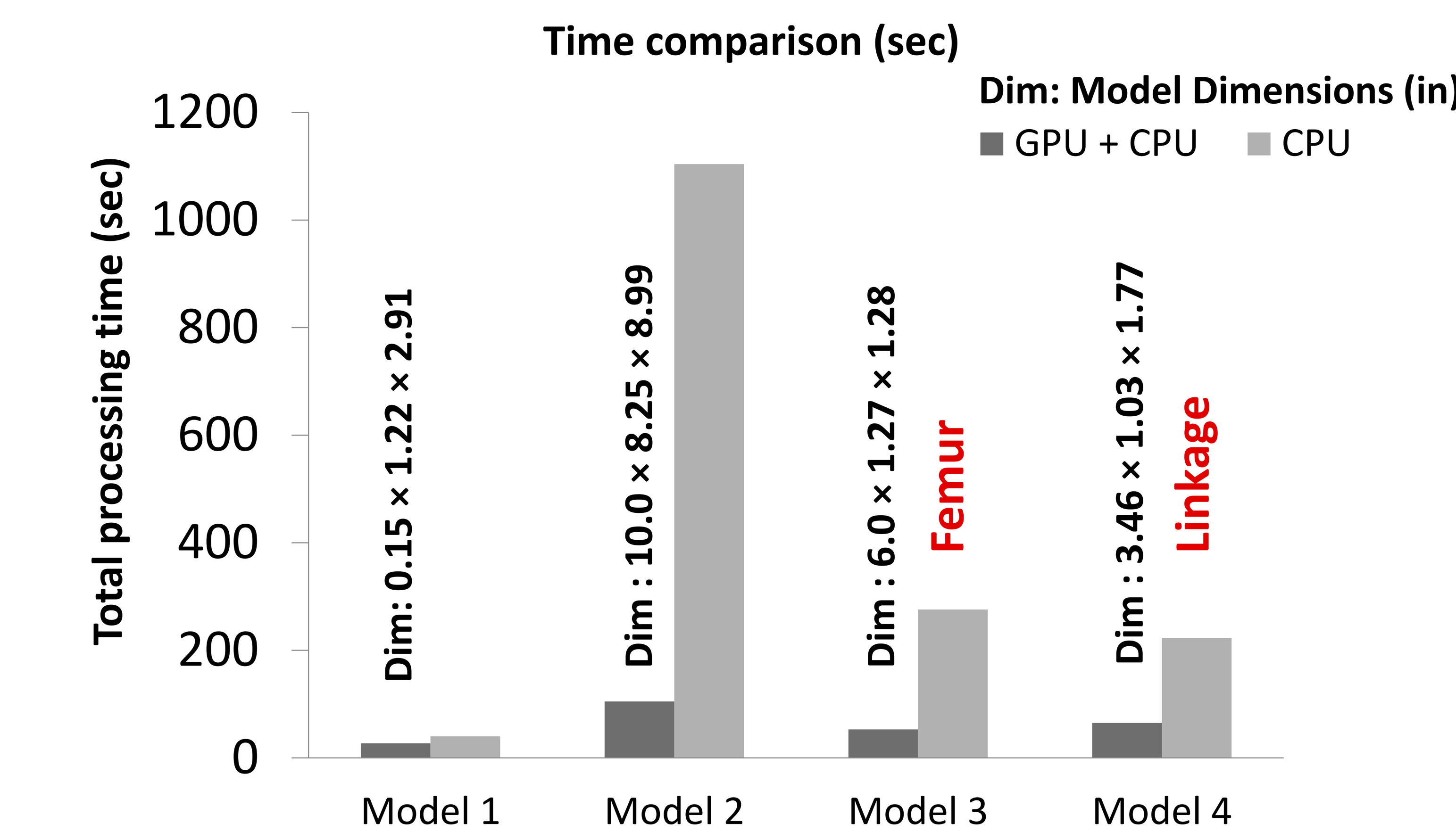
($\Theta_0 - 90, \Theta_1 - 261, \Theta_2 - 285$) **($\Theta_0 - 0, \Theta_1 - 90, \Theta_2 - 180, \Theta_3 - 270$)**

Machined Samples



Human Femur Industrial linkage

Results: GPU: Tesla-C2075/CPU: 2.90GHz, 32GB RAM



Conclusions

As the model dimensions increase, the total processing times are dramatically shorter using (GPU + CPU) vs CPU. Implementing the algorithms on the GPU allows more extensive analysis, whereby multiple manufacturability and process capabilities can be considered, while yielding better solutions faster.

References

[1] M. Frank, R. Wysk, S. Joshi, Determining Setup Orientations from the Visibility of Slice Geometry for Rapid CNC Machining, ASME J. Manuf. Sci. Eng., v 128, n 1, p 228-238,2006.

[2] Y. Li and M. Frank. “Machinability Analysis for 3-Axis Flat End Milling”, ASME J. Manuf. Sci. Eng., v 128, n 2 , p 454-464, 2006.

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