

Lucas Euzébio Machado

Parallel Algorithms for Multicore Game  
Engines

TESE DE DOUTORADO

DEPARTAMENTO DE INFORMÁTICA  
Postgraduate program in Informatics

Rio de Janeiro  
March 2010

Lucas Euzébio Machado

Parallel Algorithms for Multicore Game  
Engines

TESE DE DOUTORADO

Thesis presented to the Postgraduate Program in Informatics  
of the Departamento de Informática, PUC–Rio as partial  
fulfillment of the requirements for the degree of Doutor em  
Informática

Advisor: Prof. Bruno Feijó

Rio de Janeiro  
March 2010

**Lucas Euzébio Machado**

**Parallel Algorithms for Multicore Game  
Engines**

Thesis presented to the Postgraduate Program in Informatics,  
of the Departamento de Informática do Centro Técnico  
Científico da PUC-Rio, as partial fulfillment of the require-  
ments for the degree of Doutor.

**Prof. Bruno Feijó**

Advisor

Departamento de Informática — PUC-Rio

**Prof. Noemi Rodriguez**

Departamento de Informática — PUC-Rio

**Prof. Marcelo Dreux**

Departamento de Engenharia Mecânica — PUC-Rio

**Prof. Esteban Gonzalez Clua**

Universidade Federal Fluminense — UFF

**Prof. Cesar Tadeu Pozzer**

Universidade Federal de Santa Maria — UFSM

**Prof. José Eugenio Leal**

Coordinator of the Centro Técnico Científico da PUC-Rio

Rio de Janeiro , 19/3/2010

All rights reserved.

### Lucas Euzébio Machado

Lucas Machado graduated in Information Systems at PUC - Rio. He maintained a CAPES scholarship during his Masters and PHd degree, where he developed work applied to the area of electronic games. Currently he works teaching game programming and computer science.

#### Bibliographic data

Machado, Lucas

Parallel Algorithms for Multicore Game Engines / Lucas Euzébio Machado; advisor: Bruno Feijó. - 2010.

v., 70 f: il. ; 29,7 cm

1. Tese (Doutorado em Informática) - Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, 2010.

Inclui bibliografia.

1. Informática – Teses. 2. Computação Paralela. 3. Programação de Jogos Paralela. 4. Motores de Jogos Paralelos. I. Feijó, Bruno. II. Pontifícia Universidade Católica do Rio de Janeiro. Departamento de Informática. III. Título.

CDD: 004

To my parents.

## Acknowledgments

Special thanks to my advisor Bruno Feijó for basically everything and to my colleague and friend Rodrigo Martins for the free consulting.

## Resumo

Machado, Lucas; Feijó, Bruno. **Algoritmos Paralelos para Motores de Jogos em Multiprocessadores**. Rio de Janeiro, 2010. 70p. Tese de Doutorado — Departamento de Departamento de Informática, Pontifícia Universidade Católica do Rio de Janeiro.

Esse tese apresenta diversas técnicas sobre tecnologia paralela em jogos eletrônicos. A tese inicia apresentando diversas arquiteturas possíveis para um motor de jogos. Uma nova arquitetura é proposta, mais flexível e adequada para processadores do futuro que terão um grau maior de paralelismo. Em seguida, uma nova técnica para processar uma octree, uma estrutura de dados clássica da computação gráfica, é apresentada. As últimas técnicas apresentadas são relacionadas a detecção de colisão. Novas técnicas para processamento de grids hierárquicos e balanceamento de detecção de colisão em um conjunto de objetos são apresentadas.

## Palavras-chave

Computação Paralela; Programação de Jogos Paralela; Motores de Jogos Paralelos;

## Abstract

Machado, Lucas; Feijó, Bruno. **Parallel Algorithms for Multicore Game Engines**. Rio de Janeiro, 2010. 70p. DSc Thesis — Departamento de Informática, Pontifícia Universidade Católica do Rio de Janeiro.

This thesis presents several techniques about parallel technology on electronic games. The thesis begins presenting several possible architectures for a game engine. A new architecture is presented, more flexible and adequate for the processors of the future that will have a higher level of parallelism. Following, a new technique for processing an octree, a classic data structure for computer graphics, is presented. The last techniques presented are related to collision detection. New techniques for processing hierarchical grids and balancing collision detection on a set of objects are presented.

## Keywords

Parallel Computing; Parallel Game Programming; Parallel Game Engines;



# Contents

1	Introduction	<b>12</b>
1.1	Motivation and Objectives	12
1.2	The Organization of the thesis	14
1.3	Programming Aspects	16
2	Parallel Game Engine Architectures	<b>17</b>
2.1	A Single Threaded Game Loop	17
2.2	Synchronous Parallel Function Architecture	18
2.3	Asynchronous Parallel Function Architecture	19
2.4	Data Parallel Architecture	20
2.5	Pipeline Architecture	21
2.6	Fully Parallel Architecture	22
2.7	Some Final Conclusions	23
3	Parallel Techniques for Computer Graphics	<b>25</b>
3.1	Introduction	25
3.2	Related Work	27
3.3	An Adaptative Strategy in Two Steps	28
3.4	Node Processing in Step One	30
3.5	Node Processing in Step Two	31
3.6	Dynamic adaptation of the Split Level	37
3.7	The full Algorithm	38
3.8	Performance Results	40
3.9	Algorithm Analysis	41
3.10	Parallel Counting Sort	45
4	Parallel Techniques for Collision Detection	<b>49</b>
4.1	Broad Phase Collision Detection with Parallel Hierarchical Grids	49
4.2	Narrow Phase Collision Detecting Load Balancing	57
5	Conclusions	<b>64</b>
5.1	Main Contributions	64
5.2	Future Works	65
	Bibliography	<b>67</b>

## List of Figures

1.1	Project Gotham Racing Threads (source:[Dawson06])	13
1.2	Kameo's Threads - a more balanced task division (source:[Dawson06])	13
1.3	An octree	15
2.1	A Single Thread Game Loop	18
2.2	A Synchronous Parallel Function Architecture running on 3 cores	19
2.3	An Asynchronous Parallel Function Architecture running on 3 cores	20
2.4	A Data Parallel Architecture running on 3 cores	21
2.5	A Pipeline Architecture	22
2.6	A Fully Parallel Architecture running on 3 cores	23
3.1	Example of spatial division with quadtree. Nodes that are relevant for the frustum are marked by (*) and irrelevant ones have dashed branches.	26
3.2	A possible work distribution for the quadtree of figure 3.1 at level 1.	28
3.3	The split level of the A2SSB algorithm for $p$ processors revealing the two-step nature of the proposed algorithm	29
3.4	<i>nodeList</i> being used by the Node Processing Step One and Two	32
3.5	Intel quad-core processors. In the present work, tests are made on the Intel Core 2 Extreme Quad-core processor (a) [Intel09]	33
3.6	Only an uniform octree partition (a) is allowed by the proposed algorithm at step two.	33
3.7	Octree nodes as boxes. The numbers are the child IDs.	33
3.8	The translation matrix that is used for finding all brothers of an octree node	34
3.9	Examples of trends affecting the split level $d$ and the total idle time. At first the trend is set as true and is constantly increasing $d$ . This reduces the total idle time until we arrive at a moment where the increase of $d$ also increased the total idle time, this results in the trend being set to false and we repeat the process, but now the trend constantly decreases $d$ .	37
3.10	Performance analysis of octree node processing algorithms for an octree with 299,593 nodes and running on an Intel Core 2 Extreme Quad-core computer.	41
3.11	L2 cache misses for the proposed algorithm A2SSB (ALGO1 in Table of figure 3.10)	41
3.12	L2 cache misses for the version of A2SSB without a cache friendly strategy (ALGO2 in Table of figure 3.10)	42
3.13	Example of counting sort	46
3.14	Simple cases of the n-dimensional resource data array R.	47
3.15	The merged resource data array M from $P_1..P_4$	48

4.1	2D Grid dividing the space into equal sized cells.	50
4.2	A grid with small cell size and big objects.	51
4.3	A grid with big cell size and small objects.	52
4.4	An object may be colliding against objects in the southwest cell.	54
4.5	Simple Parallel Collision Detection.	58
4.6	The processing of the first object for each processor.	59
4.7	A better selection for each processor to handle.	60
4.8	Saving the parallel collision response results.	61
4.9	Parallel Collision Count Table.	61
4.10	Parallel Collision Count with Padding Results.	62
4.11	Cache line loading of 2 elements of a buffer.	62
4.12	Parallel Collision Count with Memory Alignment using 10.000 objects.	63
4.13	Parallel Collision Detection with Memory Alignment using 10.000 objects.	63
5.1	Results for the octree node processing with 299,593 nodes and 4 processors.	65

*...Embrace Change*

**Kent Beck.**