Cellular Automata as an Approximate Method in Structural Analysis

by

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Abstract

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This thesis deals with the mathematical idealization denoted cellular automata (CA) and the applicability of this method to structural mechanics. When using CA, all aspects such as space and time are discrete. This discrete nature of CA allows for ease of interaction with digital computers, while physical phenomena which are essentially discrete in nature can be simulated in a realistic way. The application of such a novel numerical method opens up new possibilities in structural analysis.

In this study, the fundamentals of CA are studied to determine how the parameters of the method are to be evaluated and applied to the established field of structural analysis. Attention is given to the underlying mathematics of structural mechanics, as well as approximate methods currently used in structural analysis, e.g. the finite element method (FEM) and the boundary element method (BEM).

For structural simulations performed with the CA implemented in this study, machine learning based on a genetic algorithm (GA) is used to determine optimum rules for the CA, using finite element, boundary element and analytical approximations as the basis for machine learning.

Rather unconventionally, symmetric problems in structural analysis are analyzed using asymmetric rules in the machine learning process, where the symmetry of the solution found is used as a quantitative indication of the quality of the solution. It is demonstrated that the quality of the asymmetric rules is superior to the quality of symmetric rules, even for those

problems that are symmetric in nature.

Finally, exploiting the inherent parallelism of CA, it is shown that distributed computing can greatly improve the efficiency of the CA simulation, even though the speed-up factor is not necessarily proportional to the number of sub lattices used.

The distributed computing device itself is constructed by combining 18 obsolete Pentium computers in a single cluster. In terms of CPU performance the constructed distributed computer is not state-of-the-art, but it is constructed with no hardware costs whatsoever. In addition, the software used in assembling the cluster is in the public domain, and is also available free of charge. Such a parallel configuration is also known as the poor man's computer. However, faster and more modern machines can simply be added to the existing cluster as and when they become available.

While CA are recent additions to the 'tools' used in structural analysis, increased use of CA as distributed computing becomes more widely available is envisaged, even though the CA rules are at this stage not transferable between different problems or even between meshes of varying refinement for a given problem.

Opsomming

Titel: Sellulêre Outomata as 'n Benaderingsmetode in Struktuuranalise

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Hierdie verhandeling is gemoeid met die numeriese idealiseringsmetode genoem sellulêre outomata (SO), en die moontlike toepassings van hierdie metode in struktuurmeganika. SO is 'n metode waarin alle fisiese parameters soos tyd en ruimte met diskrete waardes benader word. Die diskrete aard van SO laat eenvoudige interaksies met rekenaars toe, terwyl fisiese verskynsels wat hoofsaaklik diskreet van aard is, op 'n realistiese wyse benader kan word. Die toepassing van so 'n nuwe metode in struktuuranalise laat uiteraard nuwe moontlikhede toe.

In hierdie studie word die fundamentele werking van die SO bestudeer om te bepaal hoe die parameters van die metode benader kan word, om dan ook toegepas te kan word op die gevestigde gebied van struktuuranalise. Aandag word verder ook gegee aan die onderliggende wiskundige begrippe van struktuurmeganika, asook benaderingsmetodes wat reeds gevestig is in struktuuranalise, soos byvoorbeeld die eindige element metode (EEM) en die rand element metode (REM).

In struktuursimulasies met behulp van die SO wat ontwikkel is, word masjien-onderrig met behulp van 'n genetiese algoritme (GA) gebruik om die optimale reëls vir die SO te bepaal. Die basis vir die leerproses is eindige element modelle, rand element modelle, asook analitiese benaderings.

Simmetriese probleme in struktuuranalise word op 'n onkonvensionele manier geanaliseer met behulp van onsimmetriese reëls in die masjienonderrig proses, terwyl die simmetrie van die voorspelde oplossings gebruik word as 'n kwalitatiewe aanduiding van die geskiktheid

van die reëls. Daar word aangetoon dat die kwaliteit van onsimmetriese reëls beter is as die kwaliteit van simmetriese reëls, selfs vir die probleme wat inherent simmetries is.

Laastens, deur gebruik te maak van die inherente parallelisme van die SO, word aangetoon dat verspreide berekenings die effektiwiteit van SO-berekenings kan verhoog, alhoewel die versnellingsfaktor nie noodwendig eweredig aan die aantal onderverdelings in die struktuur is nie.

Die verspreide rekenaar is saamgestel deur 18 verouderde Pentium-rekenaars in 'n enkele berekeningsgroep saam te stel. In terme van SVE-prestasie is die verspreide rekenaar nie op die voorgrond van tegnologie nie, maar is saamgestel sonder enige hardeware koste. Die sagteware wat gebruik is om die berekeningsgroep saam te stel is in die publieke domein, en is ook kosteloos beskikbaar. So 'n parallelle rekenaar staan ook bekend as die "arm man se parallellerekenaar". Vinniger en beter rekenaars kan egter eenvoudig tot die berekeningsgroep toegevoeg word wanneer hulle beskikbaar is.

Terwyl SO 'n onlangse stuk 'gereedskap' is wat in struktuuranalise gebruik word, word verwag dat SO toenemend gebruik sal word soos verspreide berekenings meer algemeen beskikbaar raak, nieteenstaande die feit dat die reëls op hierdie stadium nie oordraagbaar is tussen verskillende probleme nie, en ook nie vir verskillende grade van maasverfyning vir 'n bepaalde probleem nie.

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I would like to dedicate this thesis to Laura Vatta.

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List of Abbreviations

1-D	One dimensional
2-D	Two dimensional
3-D	Three dimensional
BEM	Boundary element method
CA	Cellular automata
CPU	Central processing unit
CSE	Computational science and engineering
FDM	Finite difference method
FEM	Finite element method
GA	Genetic algorithm
IPC	Inter-process communications
MIMD	Multiple instruction multiple data
MPP	Massive parallel processors
NFS	Networked file system
NOW	Network of workstations
OS	Operating system
PDE	Partial differential equation
PVM	Parallel virtual machine
RISC	Reduced instruction set computing
RMS	Root mean square
SIMD	Single instruction multiple data
VLSI	Very large scale integration