Jahresbericht
im strukturierten Promotionsstudiengang

Erster Bericht (15.01.19 - 14.01.19)

vorgelegt von Florian Streitbürger

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1 Forschung

Ich habe mich im vergangenen Jahr unter Betreuung von JProf. Dr. Sandra May mit neuen Möglichkeiten zur Stabilisierung von unstetigen Galerkin Verfahren beschäftigt, die zum Lösen von hyperbolischen Erhaltungsgleichungen auf sogenannten Cut-Cell-Gittern verwendet werden. Unter Cut-Cell-Gittern verstehen wir hierbei Gitter, die entstehen wenn man das zu untersuchende Objekt aus einem äquidistanten Gitter hinausschneidet (vgl. Abb. 1). Dabei entstehen am Rand sogenannte Cut-Cells, die verschiedene Formen annehmen und beliebig klein werden können. Dadurch kommt es beim Lösen auf diesen Cut-Cells zu Instabilitäten. Das größte Problem bei hyperbolischen Erhaltungsgleichungen ist das sogenannte *Kleine-Zelle-Problem* (engl. small cell problem). Der Hintergrund des Ganzen ist, dass man zum Lösen von hyperbolischen Erhaltungsgleichungen explizite Zeitschrittverfahren verwendet. Diese unterliegen bei der Wahl der Zeitschrittweite der CFL-Bedingung. Diese besagt, dass man die Zeitschrittweite gemäß des Ortsgitters wählen muss. Wenn die Cut-Cells nun beliebig klein werden können, ist dies nicht mehr möglich. Daher wählt man die Zeitschrittweite gemäß des kartesischen Hintergrundgitters und versucht die Instabilitäten, die durch eine zu große Zeitschrittweite auf den kleinen Cut-Cells entstehen, mit geeigneten Stabilitätstermen zu neutralisieren.

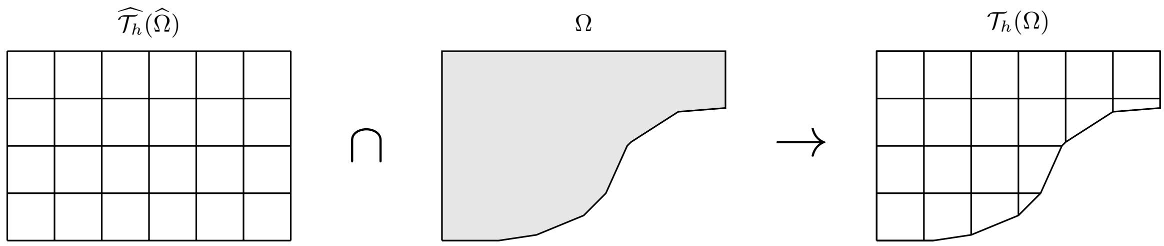

Abbildung 1: Konstruktion eines Cut-Cell-Gitters $\mathcal{T}_h(\Omega)$: Aus dem Hintergrundgitter $\widehat{\mathcal{T}_h}$ eines größeren Gebiets $\widehat{\Omega}$ wird das Simulationsgebiet Ω ausgeschnitten. Hierbei entstehen sog. Cut-Cells $E = \widehat{E} \cap \Omega$, wobei $\widehat{E} \in \widehat{\mathcal{T}_h}$ eine kartesische Hintergrundzelle ist. (Quelle: [1])

In diesem Rahmen wurden in Zusammenarbeit mit Prof. Dr. Christian Engwer von der WWU Münster die Stabilitätsterme für stückweise konstante Ansatzfunktionen, die bereits in meiner Masterarbeit bei JProf. Dr. Sandra May für eine Dimension erarbeitet und anschließend theoretisch und numerisch verifiziert wurden, auf den zweidimensionalen Fall übertragen. Hierbei wurde die C++-Bibliothek **Dune** verwendet, die von Christian Engwer mitentwickelt wurde und bereits eine gute Infrastruktur für Cut-Cell-Gitter liefert. Gleichzeitig wurden im Eindimensionalen sowohl die Wahl des Vorfaktors der Stabilisierungsterme untersucht als auch Stabilitätsterme für stückweise lineare Ansatzfunktionen entwickelt. Hierfür konnte theoretisch bewiesen werden, dass das Verfahren für stückweise lineare Funktionen unter Hinzunahme eines geeigneten Limiters eine $TVDM$(total variation diminishing in the means)-Eigenschaft erfüllt. Anschließend konnten diese Stabilitätsterme ebenfalls erfolgreich ins Zweidimensionale erweitert werden. In den numerischern Tests in einer sowie zwei Dimensionen weisen die Verfahren für beliebig kleine Cut-Cells keinerlei Instabilitäten auf. Die Fehlerordnungen liegen ebenfalls in den für Cut-Cells typischen Bereichen. Die Ergebnisse wurden im Anschluss in einem Paper

sowie einem Proceeding zusammengefasst und sind unter [1, 2] zu finden.
Weiterhin wurden die Ziele definiert, die Stabilitätsterme für höhere Polynomgrade sowie nicht-lineare Erhaltungsgleichungen zu erweitern. Hierbei liegt der Fokus auf den Euler-Gleichungen, wobei der erste Schritt die Burgers-Gleichung sein wird. Bei diesem gemeinsamen Projekt wird ein ständiger Austausch mit Christian Engwer aus Münster stattfinden. Als großes Ziel setzen wir uns Euler-Gleichungen in zwei Dimensionen für beliebig hohe Polynomgrade.

Literatur

[1] C. Engwer, S. May, C. Nüßing, and F. Streitbürger, A stabilized discontinuous Galerkin cut cell method for discretizing the linear transport equation. arXiv:1906.05642, (2019)

[2] F. Streitbürger, C. Engwer, S. May, and C. Nüßing, Monotonicity considerations for stabilized DG cut cell schemes for the unsteady advection equation arXiv:1912.11933, (2019)

2 Leistungen im Promotionsstudiengang

Leistung	Semester/ Jahr	Anl.	Name des Veranstalters	Unterschrift
Promotionsnahe Leistungen				
Teilnahme: DUNE Workshop	März 19		-	S. May
Präsentation: Hirschegg Workshop On Conservation Laws	September 19		-	S. May
Präsentation: Enumath	Oktober 19		-	S. May
Präsentation: Oberseminar LSIII	SS 19		-	S. May
Publikation: Oberwolfach Report No. 24/2019	Mai 19		-	S. May
Eingereichte Publikation: A stabilized DG cut cell method for discretizing the linear transport equation	Juni 19		-	S. May
Präsentation: Gastvortrag TU München	November 19		-	S. May
Eingereichte Publikation: Enumath Proceedings 2019	Dezember 19		-	S. May
Leistungen wissenschaftlicher Weiterbildung				
Teilnahme: HPC Programmierung mit C/C++ für MATLAB Programmierer	SS 19		I. Schulz	S. Anhang
Erwerb überfachlicher Kompentenzen				
Tutor: Numerik II	SS 19		S. Turek	[illegible]
Tutor: COP-Kurs	SS 19		S. May	S. May
Tutor: Unstetige Galerkin-Verfahren	SS 19		S. May	S. May
Teilnahme Workshop: Conference Presentation	November 2019		-	S. Anhang
Tutor: Analysis I	WS 19\20		B. Schweizer	B. [illegible]

S. May
(JProf. Dr. Sandra May)

F. Streitbürger
(Florian Streitbürger)

technische universität
dortmund

Modulbescheinigung Studium Fundamentale

Frau/Herr: Florian Streitbürger

Studiengang: Promotion Mathematik

Matrikelnummer: 165759

hat im SoSe 2019 aktiv an der Lehrveranstaltung
HPC-Programmierung mit C/C++ für MATLAB-Programmierer

der Fakultät/Einrichtung Informatik

im Rahmen des Studium Fundamentale teilgenommen.

Veranstaltungsleitung: Ingo Schulz

Anzahl der Credit Points: 2

Bemerkung/en: Die Lehrveranstaltung umfasste folgende Themen:
Einführung in C/C++ (Grundkonzepte, Arrays, Zeiger, Objektorientierung),
Einführung in Hardwarearchitektur (CPUs: Cache Hierarchien, Vektorisierung),
Performance-Engineering, Umsetzen von MATLAB-Code in C/C++ mit Code-Optimierung auf dem Hochleistungsrechner LiDO und Vergleich der Ergebnisse.

Technische Universität Dortmund
Fakultät für Informatik
1
Der Dekan

18.12.2019
Datum

Unterschrift/Stempel des Instituts

UNIVERSITÄT HEIDELBERG
Zukunft. Seit 1386.

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March 4, 2019

Confirmation of Participation

Florian Streitbürger

has attended the „DUNE/PDE Lab Course 2019" in Heidelberg from March 4 to 8, 2019 and has paid

- ○ no course fee
- ☒ reduced course fee (225 Euro)
- ○ full course fee (400 Euro)

F. Hirsch
i.A. Felicitas Hirsch

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Schedule

	Monday	Tuesday	Wednesday	Thursday	Friday
09:00 - 10:00	**Giesselmann, Jan** *A Posteriori Error Estimates of Numerical Methods for Random Hyperbolic Conservation Laws*	**May, Sandra** *Approaches for solving hyperbolic conservation laws on cut cell meshes*	**Hike**	**Hantke, Maren** *Modelling Phase Transition with the Baer-Nunziato Model*	**Klein, Rupert** *Well-balanced and scale-dependent time integration for atmospheric flows*
10:00 - 10:30	***Coffee Break***	***Coffee Break***		***Coffee Break***	***Coffee Break***
10:30 - 11:15	**Joshi, Hrishikesh** *Model adaptation for hyperbolic balance laws*	**Streitbürger, Florian** *A stabilized DG cut cell method for discretizing the linear transport equation*		**Matern, Christoph** *The Riemann problem for a weakly hyperbolic two-phase flow model of a dispersed phase in a carrier fluid*	**Hastermann, Gottfired** *Towards robust numerical methods for combined model and data dynamics of atmospheric models with multiple scales*
11:15 - 12:00	**Gerster, Stephan** *Stochastic Galerkin Formulations for Hyperbolic Conservation Laws*	**Kerkmann, David** *Active Flux Methods for Hyperbolic Conservation Laws - ADER Interpretation and Application to Cut Cells Meshes*		**Yaghi, Hazem** *Riemann problem for a diffuse interface multiphase mixture model*	**Dörffel, Tom** *Energy Balances of Tropical Cyclones: Generation of Available Potential and Kinetic Energy by Diabatic Heating*
12:30 - 14:30	***Lunch Break***	***Lunch Break***		***Lunch Break***	***Lunch Break***
14:30 - 15:15	**Kerkhoff, Xenia** *Commutative properties of space-time DG schemes for optimal control problems constrained by convection diffusion equations*	**Barsukow, Wasilij** *The low Mach number limit of the Active Flux scheme*		**Hike**	**Mantri, Yogiraj** *High order well-balanced schemes for flows in networks*
15:15 - 16:00	**Müller, Siegfried** *Multiwavelet-Based Grid Adaptation with Discontinuous-Galerkin schemes for Conservation Laws*	**Minakowski, Piotr** *On the Euler System with Variable Congestion and application to crowd dynamic*			**Borsche, Raul** *Kinetic layers and coupling conditions for hyperbolic PDEs on networks*
16:00 -	***Coffee Break***	***Coffee Break***			***Coffee Break***

16:30					
16:30 - 17:15	**Ni, Guoxi** *Adaptive Multi-resolution Interface Method for Three Dimensional Reacting Flow*	**Hayat, Adnan** *Theoretical analysis of forced segmented temperature gradients in liquid chromatography*			**Holle, Yannick** *Kinetic coupling conditions for isentropic flows on networks*
17:15 - 18:00					**Zacharenakis, Dimitrios** *Asymptotic preserving (AP) schemes for gas flows on large networks*
				After Dinner, 20:00: **Warnecke, Gerald** *C.F. Gauß and Geodesy*	

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Letzte Änderung: 10.09.2019 - Ansprechpartner: [Dr. Ferdinand Thein] login

European Numerical Mathematics and Advanced Applications Conference 2019
30th sep - 4th okt 2019, Egmond aan Zee, The Netherlands

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15:45 Isogeometric Analysis and Fluid Structure Interaction (Part 3)
Chair: Anotida Madzvamuse

15:45 **A minimal set of unisolvent weights for high-order Whitney forms on simplices**
25 mins *Ana Alonso Rodriguez, Ludovico Bruni Bruno, Francesca Rapetti*
Abstract: Whitney elements on simplices are widely used finite elements in computational electromagnetics (see [2] and [1]) as they offer the simplest construction of polynomial discrete differential forms on simplicial complexes. In the lowest order case (that is, coefficients are polynomials of degree one), the associated degrees of freedom are the integrals of such k-forms on the k-simplices of the mesh and consequently bear some physical information. However, the classical degrees of freedom used for high order Whitney forms (see, e.g., [4]), the so-called moments, lack this meaning. For this reason, in [5] an alternative set of degrees of freedom, which we refer to as weights, is introduced. Namely, such degrees of freedom read as the integrals of k-forms on the small k-simplices that are built upon the principal lattice of the elements. In [3] it is proved that this set of weights induces unisolvent degrees of freedom. However they are redundant: their number exceeds the dimension of the space of differential forms. In this work, we show that a particular subset of this weights with cardinality equal to the dimension of the space of differential forms is still unisolvent.

16:10 **Goal-Oriented A Posteriori Error Estimates for Elliptic Problems discretized by the Discontinuous Galerkin Method**
25 mins *Ondřej Bartoš, V. Dolejší*
Abstract: We deal with the numerical solution of linear elliptic problems using the discontinuous Galerkin method with focus on the goal-oriented a posteriori error estimates. The aim is to estimate the error of the quantity of interest represented by a linear functional. The abstract error estimate is based on the knowledge of the (exact) solution z of the dual problem corresponding to the primal one. In order to de_ne a computable estimate, the dual solution z has to be replaced by its approximation z+ h and the remaining term represented by di_erence z z+ h is usually neglected. In this presentation we propose an approach which estimates the neglected term. Consequently, we are able to derive a guaranteed error estimate. This type of estimates are known for the conforming _nite element approximation but it is new in the framework of discontinuous Galerkin method. Moreover, we introduce an e_cient implementation approach allowing a simultaneous solution of the primal and dual problems. Finally, several numerical examples will be presented.

16:35 **Monotonicity considerations for stabilized DG cut cell schemes for the unsteady advection equation**
25 mins *Florian Streitbürger, Christian Engwer, Sandra May, Andreas Nüßing*
Abstract: For solving unsteady hyperbolic conservation laws on cut cell meshes, the so called small cell problem is a big issue: one would like to use a time step that is chosen with respect to the background mesh and use the same time step on the potentially arbitrarily small cut cells as well. For explicit time stepping schemes this leads to instabilities. In a recent preprint [arXiv:1906.05642], we propose penalty terms for stabilizing a DG space discretization to overcome this issue for the unsteady linear advection equation. The usage of the proposed stabilization terms results in stable schemes of first and second order in one and two space dimensions. In one dimension, for piecewise constant data in space and explicit Euler in time, the stabilized scheme can even be shown to be monotone. In this contribution, we will examine the conditions for monotonicity in more detail.

17:00 **Finite Element Approximation of the Spectrum of the Curl Operator**
25 mins *Ana Alonso Rodriguez, Jessika Camano, Rodolfo Rodriguez, Alberto Valli, Pablo Venegas*
Abstract: The presentation concerns the formulation and analysis of the eigenvalue problem for the curl operator in a multiply connected domain and its numerical approximation by means of finite elements. Different boundary conditions that render the curl operator self-adjoint are taken into account. I will focus on those boundary conditions that in particular impose ${\rm curl} \, {\bf u} \cdot {\bf n}=0$. In the case of a multiply connected domain, different contributions from co-homology spaces distinguish different self-adjoint extensions. This distinction can be made by imposing the vanishing of the line integrals on suitable homological cycles lying on the boundary. A saddle-point variational formulation is devised and analyzed, and a finite element numerical scheme is proposed. It is proved that eigenvalues and eigenfunctions are efficiently approximated and some numerical results are presented in order to assess the performance of the method.

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Stabilized dG-methods for solving the linear advection equation on embedded boundaries

Florian Streitbürger[1]

Joint work: Sandra May[1], Christian Engwer[2], Andreas Nüßing[2]

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[2]Applied Mathematics Münster, WWU Münster

07.05.2019

for short. The definitions above ensure that $\mathcal{V}_\alpha(t,x) \in [0, V_{\max}]$ for all $i = 1, \ldots, n$, $t \in [0,T]$ and $x \in \mathbb{R}^n$.

We now introduce a condition that states the absence of collisions among drivers:

$$\textbf{(NoCollision):}\ \forall \alpha', \alpha'' \in \{1, \ldots, n\}, \text{ if } r_{\alpha'} = r_{\alpha''}, \text{ then } |x_{\alpha'} - x_{\alpha''}| \geq \ell.$$

The following main result holds (see [1] for the proof):

Theorem 1. *Consider a network of m (with $m \in \mathbb{N} \setminus \{0\}$) interconnected roads containing at least one Entry Road and one Exit Road. For $j = 1, \ldots, m$, on road j a speed law v_j satisfying* ***(SpeeedLaw)*** *is given. Assign to n (with $n \in \mathbb{N} \setminus \{0\}$) drivers routes $\mathcal{R}_1, \ldots, \mathcal{R}_n$ satisfying the* ***(NoLoop)*** *and* ***(NoDeadEnd)*** *conditions. Each driver α is assigned an initial position x_α in the first road of the α's route $\mathcal{R}_\alpha$ and these initial positions satisfy condition* ***(NoCollision)****.*
Then, the differential equation (1) *admits a unique solution on the time interval $[0, +\infty[$. Moreover, at any positive t, the positions $x_\alpha(t)$ of the drivers at time t along roads $r_\alpha(t)$, keep satisfying condition* ***(NoCollision)****.*

References

[1] R.M. Colombo, H. Holden, F. Marcellini, *On the Microscopic Modeling of Vehicular Traffic on General Networks*, Preprint (2019).

[2] D.C. Gazis, R. Herman and R.W. Rothery, *Nonlinear Follow-the-Leader Models of Traffic Flow*, Operations Res. **9** (1961), 545–567.

A stabilized DG cut Cell Method for discretizing the Linear Transport Equation

Sandra May

(joint work with Christian Engwer, Andreas Nüßing, Florian Streitbürger)

Abstract. The generation of body-fitted, unstructured meshes can be very time-consuming for domains that involve objects with complex geometries. Therefore, unfitted or embedded boundary methods have become very popular in recent years. In our approach, we simply cut the object out of a standard (Cartesian) background mesh, resulting in so called *cut cells* along the boundary of the embedded object. Cut cells have various shapes and can become arbitrarily small.

When solving time-dependent, hyperbolic conservation laws, a big issue is the *small cell problem*: standard explicit time stepping schemes are not stable on the arbitrarily small cut cells if the time step is chosen according to the background mesh. Therefore, one needs special schemes. In the context of finite volume schemes, there already exist several approaches for solving this issue. In the context of discontinuous Galerkin (DG) schemes however we do not know of any approach that does not rely on merging small cut cells with their bigger neighbors.

We suggest new stabilization terms to overcome the small cell problem for the linear advection equation in two dimensions for DG schemes with piecewise linear polynomials. Our stabilization is designed to only let a certain fraction of the

Betreff: ENUMATH2019: Full Paper notification
Von: info@enumath2019.eu
Datum: 20.04.20, 16:23
An: florian.streitbuerger@math.tu-dortmund.de

Dear Florian Streitbuerger,

We are very pleased to inform that your full paper for the ENUMATH2019 proceedings

Nr. 535: Monotonicity considerations for stabilized DG cut cell schemes for the unsteady advection equation by Florian Streitbürger, Christian Engwer, Sandra May, Andreas Nüßing,

has been ACCEPTED in its present state.

In case there are any comments of the reviewer(s) you can find them at the end of this message. If you wish to make some changes you can overwrite the old version of the paper by a new one before May 31, 2020.

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With kind regards,
Fred Vermolen
Conference chair

===
Review Results
Title: Monotonicity considerations for stabilized DG cut cell schemes for the unsteady advection equation
Tracking Number: 535
Verdict: Accepted
================== Review Results ==============================

Comments to Authors:
Dear authors,

the manuscript is well written and nicely complements the paper [1]. I therefore recommend it for publication in the ENUMATH proceedings with only very minor adjustments:

1) p.2: please remove the word "as" just before equation (1).

2) p.5: please use consistent notation: "ghost penalty method" vs. "ghost-penalty method"

3) p. 5-6: please use consistent notation: J_h^{GP} vs. $J_h^{\rm GP}$ and same for system matrix $\mathcal{B}_{GP}$ vs. $\mathcal{B}_{\rm GP}$

4) p. 6: please remove the extra space "stabilization [ ], which we introduced in [1]"

5) In remark 1 the authors state that "this [choice] produces better results for piecewise linear polynomials". Is it possible to make this statement more concrete?

With respect to which criteria do the authors consider the solution to be "better"? Is
is more accurate, less pronounced over/undershoots, ...