13th International Workshop on Variational Multiscale and Stabilized Finite Elements

Weierstrass Institute for Applied Analysis and Stochastics

Berlin, December 5 - 7, 2018

www.wias-berlin.de/workshops/VMS2018

Organizers:

Alfonso Caiazzo

Volker John

Alexander Linke

Ulrich Wilbrandt

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Weierstrass Institute for Applied Analysis and Stochastics

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Dyn-Sim-FP

DYNAMISCHE SIMULATION VERNETZTER FESTSTOFFPROZESSE

SPP 1679

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Contents

General information

The general framework for the numerical modeling of multiscale phenomena with variational multiscale (VMS) methods was proposed in the 1990-s by the seminal papers of T.J.R. Hughes (1995) and J.-L. Guermond (1999). One of the fields where the ideas of VMS methods have been applied are problems from Computational Fluid Dynamics (CFD). In 2004, G. Lube (Göttingen, Germany) organized a small workshop, which turned out to be the first one in the series of VMS workshops, to discuss these new VMS ideas and their relations to other stabilized methods. As a result of this workshop, a survey paper on stabilized finite element methods for the Oseen equations was compiled (2007). Based on the very good atmosphere of each of the preceeding workshops and driven by an active community, the VMS workshop series was continued. After the 12th workshop in this series, which took place in Seville 2017, five contributions of participants were published in a special issue of the SeMA Journal 2018.

In the course of the years, the range of topics became broader than the traditional title of the workshop series suggested. Nowadays, the workshops are a platform for discussing all kinds of stabilized methods for the numerical simulation of partial differential equations, where still problems from CFD are particularly in the focus of the community. As well new results from numerical analysis of such methods as their use for the simulation of problems from applications are of interest.

The 13th VMS workshop is organized in Berlin. There are still many unresolved problems concerning the construction of appropriate numerical methods for multiscale problems, the numerical analysis of stabilized methods, and their assessment in numerical simulations. The research at these topics will hopefully form the basis for a further continuation of this successful workshop series.

WIAS

Weierstrass Institute
Mohrenstraße 39
10117 Berlin

Places to have lunch, see page 30:
The following list contains a selection of places to eat and drink in the vicinity of WIAS. Many members of WIAS spend their lunch break in the canteen of Konzerthaus am Gendarmenmarkt (numer (1) in the list). The entrance is via Taubenstraße, 2nd floor.

Program

Wednesday, 05.12.2018	
12:30 - 13:45	REGISTRATION
13:45 - 14:00	OPENING
14:00	**Julia Novo (Madrid)** Symmetric pressure stabilization for equal order finite element approximations to the time-dependent Navier–Stokes equations (see page 22)
14:35	**Utku Kaya (Kiel)** Local pressure corrections for Stokes system (see page 16)
15:10 - 15:40	COFFEE BREAK
15:40	**Laura Blank (Berlin)** A robust finite element method for the Brinkman problem (see page 13)
16:15	**Alexander Linke (Berlin)** On high-order pressure-robust space discretisations, their advantages for incompressible high Reynolds number generalised Beltrami flows and beyond (see page 18)

Thursday, 06.12.2018	
09:00	**Gert Lube (Göttingen)** On the hypotheses of Boussinesq and Onsager and the link to implicit large eddy simulation (see page 19)
09:35	**Christian Merdon (Berlin)** Well-balanced discretisation of the compressible Stokes problem (see page 20)
10:10 - 10:40	COFFEE BREAK
10:40	**Philipp W. Schroeder (Göttingen)** Simulation of 3D turbulent incompressible flows with high-order Discontinuous Galerkin methods (see page 24)
11:15	**Petr Knobloch (Prague)** Algebraic flux correction and the discrete maximum principle (see page 17)
11:40 - 14:00	LUNCH
14:00	**Daniel Peterseim (Augsburg)** Sparse compression of expected solution operators (see page 23)
14:35	**Marius Paul Bruchhäuser (Hamburg)** Adaptive methods and efficient data structures for stabilized finite flement methods (see page 14)
15:10 - 15:40	COFFEE BREAK
15:40	**Andriy Sokolov (Bochum)** A flux-corrected RBF-FD method for convection dominated problems in domains and on manifolds (see page 25)
16:15	**Abhinav Jha (Berlin)** Investigation of different solvers for nonlinear algebraic stabilizations of convection-diffusion equations (see page 15)
18:30 - 21:30	DINNER

For information on the workshop dinner see page 32.

Friday, 07.12.2018	
09:00	**Gabriel Barrenechea (Glasgow)** The multiscale hybrid-mixed finite element method in polygonal meshes (see page 12)
09:35	**Kamel Nafa (Muscat)** Equal-order fnite elements for melt transport (see page 21)
10:10 - 10:40	COFFEE BREAK
10:40	**Ulrich Wilbrandt (Berlin)** An assessment of some solvers for saddle point problems emerging from the incompressible Navier–Stokes equations (see page 26)

Abstracts

The multiscale hybrid-mixed finite element method in polygonal meshes

Barrenechea, Gabriel (07.12.2018, 09:00)
University of Strathclyde, UK

In this talk the recent extension of the Multiscale Hybrid-Mixed (MHM) method, originally proposed in [1], to the case of general polygonal meshes (that can be non-convex and non-conforming as well) will be presented. We present new stable multiscale finite elements such that they preserve the well-posedness, super-convergence and local conservation properties of the original MHM method under mild regularity conditions on the polygons. More precisely, we show that piecewise polynomial of degree $k-1$ and k, $k \geq 1$, for the Lagrange multipliers (flux) along with continuous piecewise polynomial interpolations of degree k posed on second-level sub-meshes are stable if the latter is refined enough. Such one- and two-level discretization impact the error in a way that the discrete primal (pressure) and dual (velocity) variables achieve super-convergence in the natural norms under extra local regularity only. Numerical tests illustrate theoretical results and the flexibility of the approach.

This work has been carried out in collaboration with Fabrice Jaillet (Lyon 1, France), Diego Paredes (UCV, Valparaiso, Chile), and Frederic Valentin (LNCC, Brazil).

References

[1] Araya, R., Harder, C. , Paredes, D. and Valentin, F.: Multiscale hybrid-mixed method. SIAM *Journal on Numerical Analysis*, 51(6), 3505–3531, (2013).

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A robust finite element method for the Brinkman problem

Blank, Laura (05.12.2018, 15:40)
Weierstraß-Institut, Germany

This talk is concerned with the numerical simulation of fluid flow through porous media. The model of interest, the Brinkman model, enables the transition between the Darcy model and the Stokes model. In order to create a robust finite element method, stabilized equal-order elements together with weakly imposed essential boundary conditions are considered. Here, the focus is on a low-order approach such that element-wise linear polynomials are chosen for the velocity space as well as for the pressure space and the penalty-free non-symmetric Nitsche method is employed in order to handle the boundary conditions. Focusing on the two-dimensional case, the resulting robust finite element formulation can be proven to be unconditionally stable and yields optimal a priori error estimates in a mesh-dependent norm [1].

References

[1] Blank, L., Caiazzo, A., Chouly, F., Lozinski, A. and Mura, J.: Analysis of a stabilized penalty-free Nitsche method for the Brinkman, Stokes, and Darcy problems, WIAS Preprint 2489, In ESAIM: Mathematical Modelling and Numerical Analysis accepted (2018).

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Adaptive methods and efficient data structures for stabilized finite flement methods

Bruchhäuser, Marius Paul (06.12.2018, 14:35)
Helmut-Schmidt-Universität / Universität der Bundeswehr, Germany

The numerical approximation of nonstationary convection-diffusion-reaction problems

$$\partial_t u - \nabla \cdot (\varepsilon \nabla u) \boldsymbol{b} \cdot \nabla u \alpha u = f \tag{1}$$

with a small diffusion coefficient $0 < \varepsilon \ll 1$ remains to be a challenging task [3]. Solving those problems numerically naively by standard Galerkin finite element approximations leads to perturbed solutions with spurious unphysical oscillations. To reduce those oscillations close to regions with sharp inner or boundary layers, stabilization concepts are applied to the finite element approximations. Beside those stabilization concepts the application of adaptive mesh refinement has been considered in the past to further eliminate oscillations.

In this contribution we combine stabilized finite element methods with an a posteriori error control mechanism based on a dual weighted residual approach [1]. The dual weighted error estimator assesses the discretization error with respect to a given goal quantity of physical interest. Flexible data structures for the open source *deal.II* library are presented that are indispensable to handle the complex framework for solving the primal and dual problem in the course of the DWR philosophy. In particular, these structures offer huge potential for the application to large scale problems of practical interest. We present the derivation of our adaptive algorithm for SUPG stabilized approximations of Eq. (1). In numerical experiments its applicability is studied and demonstrated for benchmark problems of convection-dominated transport; cf. [2, 4].

References

[1] Bangerth, W., Rannacher, R.: Adaptive finite element methods for differential equations. Birkhäuser, Basel, 2003.

[2] Bruchhäuser, M.P., Schwegler, K., Bause, M.: Numerical study of goal-oriented error control for stabilized finite element methods. In Apel, T. et al. (eds.) Advanced Finite Element Methods with Applications, Lecture Notes in Computational Science and Engineering, accepted (2018), pp. 1-19. arXiv:1803.10643.

[3] John, V., Knobloch, P., Novo, J.: Finite elements for scalar convection-dominated equations and incompressible flow problems: a never ending story?. Comput. Visual. Sci., in press, 2018, https://doi.org/10.1007/s00791-018-0290-5.

[4] Köcher, U., Bruchhäuser, M. P., Bause, M.: Efficient and scalable data structures and algorithms for goal-oriented adaptivity of space-time FEM codes. In progress, 1–6 (2018).

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Investigation of different solvers for nonlinear algebraic stabilizations of convection-diffusion equations

Jha, Abhinav (06.12.2018, 16:15)
Weierstraß-Institut, Germany

Algebraic stabilizations, also called Algebraic Flux Correction (AFC) schemes, belong to the very few finite element discretizations of steady-state convection-diffusion equations that obey the discrete maximum principle. However, appropriate limiters depend on the solution itself, thus leading to a nonlinear discrete problem. The efficient solution of these nonlinear problems seems currently to be the biggest drawback in the application of these schemes.

In this talk, several methods for solving the nonlinear problems are discussed. The focus is particularly on fixed point iterations and Newton's method, thereby discussing regularizations of the limiters to obtain differentiable expressions. The methods are compared on parameters such as number of iterations and the time taken to solve the problem. Two limiters will be considered, the traditional Kuzmin limiter and a recently proposed limiter that is linearity preserving, i.e. the BJK limiter. Different algorithmic components such as Anderson acceleration, dynamic damping and projection to admissible values will also be discussed. Numerical examples from 2d as well as 3d assess the different iterative schemes.

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Local pressure corrections for Stokes system

Kaya, Utku (05.12.2018, 14:35)
Christian-Albrechts-Universität zu Kiel, Germany

Models for incompressible flows are of saddle point type and they possess a coupling between pressure and velocity variables. Pressure correction methods overcome this major difficulty -for time dependent models- by decoupling the momentum equation from the continuity equation. The common approach is:

(i) compute a not necessarily divergence-free velocity field,

(ii) solve a Poisson problem for pressure and

(iii) project the previously computed velocity onto a divergence free one.

We present a domain decomposition method that replaces the pressure Poisson problem from step (ii) with local pressure Poisson problems on each sub-region. Since no communication between the sub-regions is needed, the method is favorable for parallel computing. We point out the basic assumptions, which ensure that this localization procedure does not harm accuracy. Theoretical results are supported by numerical experiments.

Joint work with Malte Braack.

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Algebraic flux correction and the discrete maximum principle

Knobloch, Petr (06.12.2018, 11:15)
Charles University, Czech Republic

The aim of this talk is to discuss properties of algebraic flux correction (AFC) schemes, in particular, applied to convection-diffusion-reaction equations, but also in general. A special attention will be paid to conditions assuring the validity of the discrete maximum principle (DMP) which will be compared also with those used for analyzing other nonlinear stabilization techniques. Several examples of limiters used in AFC schemes will be presented and the validity of the DMP will be investigated. Numerical results will illustrate the theoretical considerations. This is a joint work with G.R. Barrenechea (Glasgow) and V. John (Berlin).

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On high-order pressure-robust space discretisations, their advantages for incompressible high Reynolds number generalised Beltrami flows and beyond

Linke, Alexander (05.12.2018, 16:15)
Weierstraß-Institut, Germany

Recently, high-order space discretisations were proposed for the numerical simulation of the incompressible Navier–Stokes equations at high Reynolds numbers, even for complicated domains from simulation practice. Although the overall spatial approximation order of the algorithms depends on the approximation quality of the boundary (often not better than third order), competitively accurate and efficient results were reported. In this contribution, first, a possible explanation for this somewhat surprising result is proposed: the velocity error of high-order space discretisations is more robust against quantitatively large and complicated pressure fields than low-order methods. Second, it is demonstrated that novel pressure-robust methods are significantly more accurate than comparable classical, non-pressure-robust space discretisations, whenever the quadratic, nonlinear convection term is a nontrivial gradient field like in certain generalised Beltrami flows at high Reynolds number. Then, pressure-robust methods even allow to halve the (formal) approximation order without compromising the accuracy. Third, classical high-order space discretisations are outperformed by pressure-robust methods whenever the boundary is not approximated with high-order accuracy. This improved accuracy of (low-order) pressure-robust mixed methods is explained in terms of a Helmholtz–Hodge projector, which cancels out the nonlinear convection term in any generalised Beltrami flow, since it is a gradient field. The numerical results are illustrated by a novel numerical analysis for pressure-robust and classical space discretisations. Further, the relevance of these results is discussed for flows that are not of Beltrami type.

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On the hypotheses of Boussinesq and Onsager and the link to implicit large eddy simulation

Lube, Gert (06.12.2018, 09:00)
Georg-August-Universität Göttingen, Germany

The Boussinesq hypothesis basically tells us that the Reynolds stress tensor is positive definite in the mean, at least under certain smoothness assumptions of the solutions of the incompressible Navier–Stokes problem. The Onsager hypothesis shows that a certain minimal smoothness of the solutions is required. The proof relies on the Reynolds stress tensor. We will show for two cases that implicit LES within a hybrid H(div)-conforming dG-FEM can provide a reasonable approximation of the Reynolds stress tensor.

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Well-balanced discretisation of the compressible Stokes problem

Merdon, Christian (06.12.2018, 09:35)
Weierstraß-Institut, Germany

This talk suggest a novel well-balanced discretization of the stationary compressible Stokes problem that has a number of interesting properties. First, the upwind-stabilisation discretization of the continuity equation and a pseudo time integration for the density ensures existence of a discrete solution and non-negativity of the discrete density. Second, a reconstruction operator is used in the discretization of the right-hand side functional(s) that maps discretely divergence-free testfunctions to divergence-free ones. This ensures a certain well-balanced property in the sense that arbitrary gradient forces are balanced by the discrete pressure as long as there is enough mass to compensate them. Moreover, if the Mach number converges to zero, the scheme converges to a pressure-robust discretization of the incompressible Stokes problem. All properties are demonstrated in several numerical examples.

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Equal-order fnite elements for melt transport

Nafa, Kamel (07.12.2018, 09:35)
Sultan Qaboos University, Oman

Mantle convection and melt migration are important processes for understanding Earth's dynamics and how they relate to the observations at the surface. Recent studies of geodynamics have shown that melt migration can be modeled by coupling variable-viscosity Stokes flow and Darcy flow. Where, Stokes flow, generally, captures the long-term behavior of the mantle and lithosphere while Darcy flow models the two-phase regime. Dannberg and Heister (2016) derived such a model for 2D and 3D simulations. However, the model they used require the so-called compaction pressure as an additional unknown in the system which does not only increases the dimension of the system, but also makes the underlying operator non-coercive. Approximating the solution using the finite element method requires the use of mixed inf-sup stable elements or additional stabilization terms. Here, we propose a formulation with a coercive non-symmetric linear operator which allow the use of simple equal-order elements.

(This work was done in collaboration with Malte Braack and Simon Taylor from the University of Kiel, Germany.)

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Symmetric pressure stabilization for equal order finite element approximations to the time-dependent Navier–Stokes equations

Novo, Julia (05.12.2018, 14:00)
Universidad Autónoma de Madrid, España

Non inf-sup stable finite element approximations to the incompressible Navier–Stokes equations based on equal order spaces for velocity and pressure are studied in this paper. To account for the violation of the discrete inf-sup condition, different types of symmetric pressure stabilization terms are considered. It is shown in the numerical analysis that these terms also stabilize dominating convection in the following sense: error bounds with constants independent of inverse powers of the viscosity are derived.

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Sparse compression of expected solution operators

Peterseim, Daniel (06.12.2018, 14:00)
Universität Augsburg, Germany

We show that the expected solution operator of prototypical linear elliptic partial differential operators with random coefficients is well approximated by a computable sparse matrix. This result is based on a random Localized Orthogonal multiresolution Decomposition of the solution space inspired by the Variational MultiScale method. This decomposition allows both the sparse approximate inversion of the random operator represented in this basis as well as its stochastic averaging. The approximate expected solution operator can be interpreted in terms of classical Haar wavelets. When combined with a suitable sampling approach for the expectation, this construction leads to an efficient method for computing a sparse representation of the expected solution operator.

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Simulation of 3D turbulent incompressible flows with high-order Discontinuous Galerkin methods

Schroeder, Philipp W. (06.12.2018, 10:40)
Georg-August-Universität Göttingen, Germany

In this talk we present numerical results for the computation of 3D turbulent incompressible flows – the Taylor–Green vortex and the turbulent channel flow at various friction Reynolds numbers are considered. We focus on the case of highly under-resolved simulations and show that high-order DG methods are very well able to capture the essential flow features in an implicit LES setting. More precisely, the performance of an exactly divergence-free H(div)-(H)DG method is compared to a stabilised L2-DG method and some differences and similarities are highlighted. Furthermore, we discuss the concept of (implicit) dissipation mechanism in DG methods and call attention to possible ambiguities in what is frequently understood as "molecular dissipation".

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A flux-corrected RBF-FD method for convection dominated problems in domains and on manifolds

Sokolov, Andriy (06.12.2018, 15:40)
Technische Universität Dortmund, Germany

We present an FCT stabilized Radial Basis Function (RBF)-Finite Difference (FD) method for the numerical solution of convection dominated problems. The proposed algorithm is designed to maintain mass conservation and to guarantee positivity of the solution for an almost random placement of scattered data nodes. The method can be applicable both for problems defined in a domain or if equipped with level set techniques, on a stationary manifold. We demonstrate the numerical behavior of the method by performing numerical tests for the solid-body rotation benchmark in a unit square and for a transport problem along a curve implicitly prescribed by a level set function. Extension of the proposed method to higher dimensions is straightforward and easily realizable.

Contributors: Dmitri Kuzmin, Oleg Davydov and Stefan Turek

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An assessment of some solvers for saddle point problems emerging from the incompressible Navier–Stokes equations

Wilbrandt, Ulrich (07.12.2018, 10:40)
Weierstraß-Institut, Germany

Efficient incompressible flow simulations, using inf-sup stable pairs of finite element spaces, require the application of efficient solvers for the arising linear saddle point problems. This paper presents an assessment of different solvers: the sparse direct solver UMFPACK, the flexible GMRES (FGMRES) method with different coupled multigrid preconditioners, and FGMRES with Least Squares Commutator (LSC) preconditioners. The assessment is performed for steady-state and time-dependent flows around cylinders in 2d and 3d. Several pairs of inf-sup stable finite element spaces with second order velocity and first order pressure are used. It turns out that for the steady-state problems often FGMRES with an appropriate multigrid preconditioner was the most efficient method on finer grids. For the time-dependent problems, FGMRES with LSC preconditioners that use an inexact iterative solution of the velocity subproblem worked best for smaller time steps.

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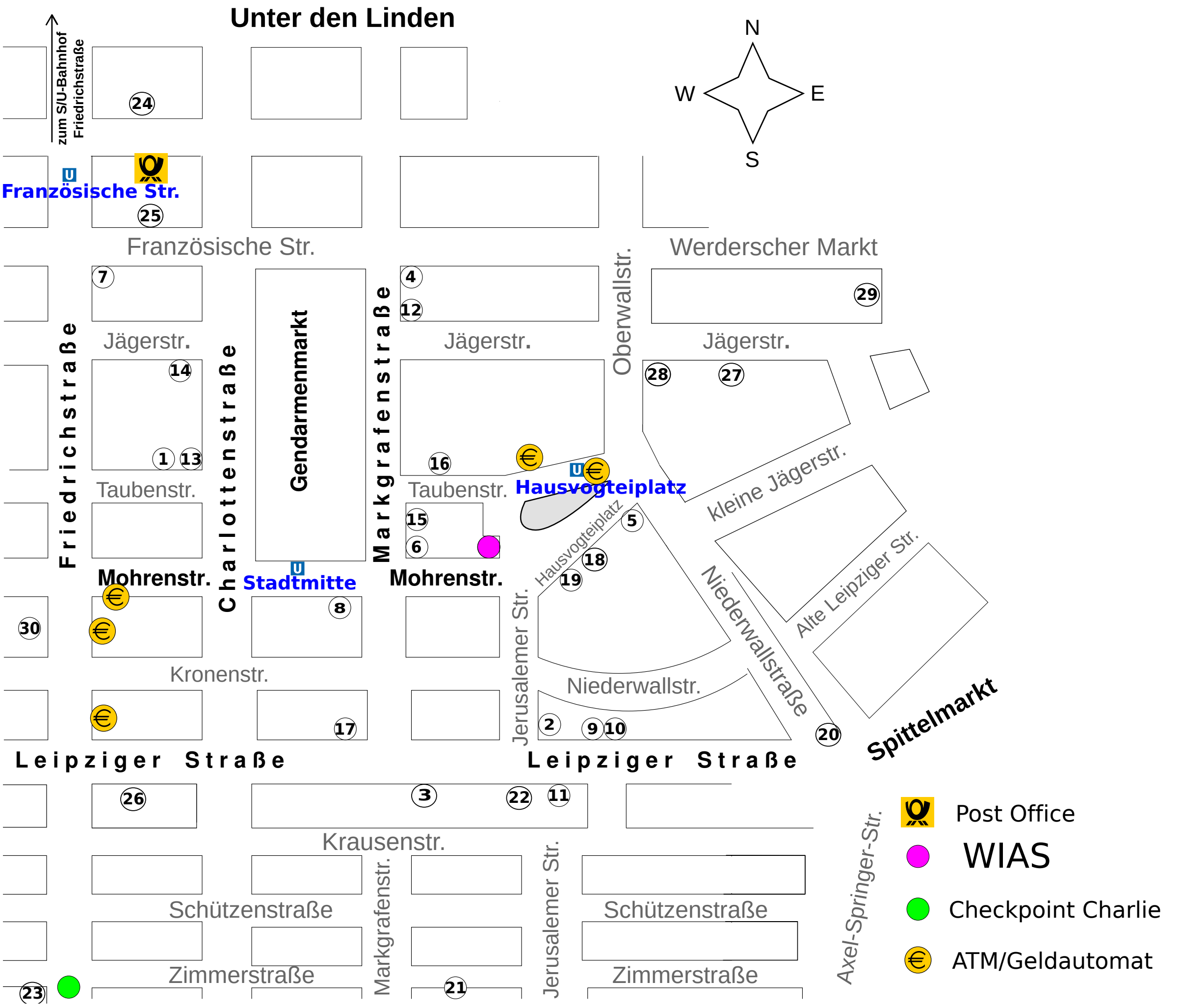
Places to have lunch



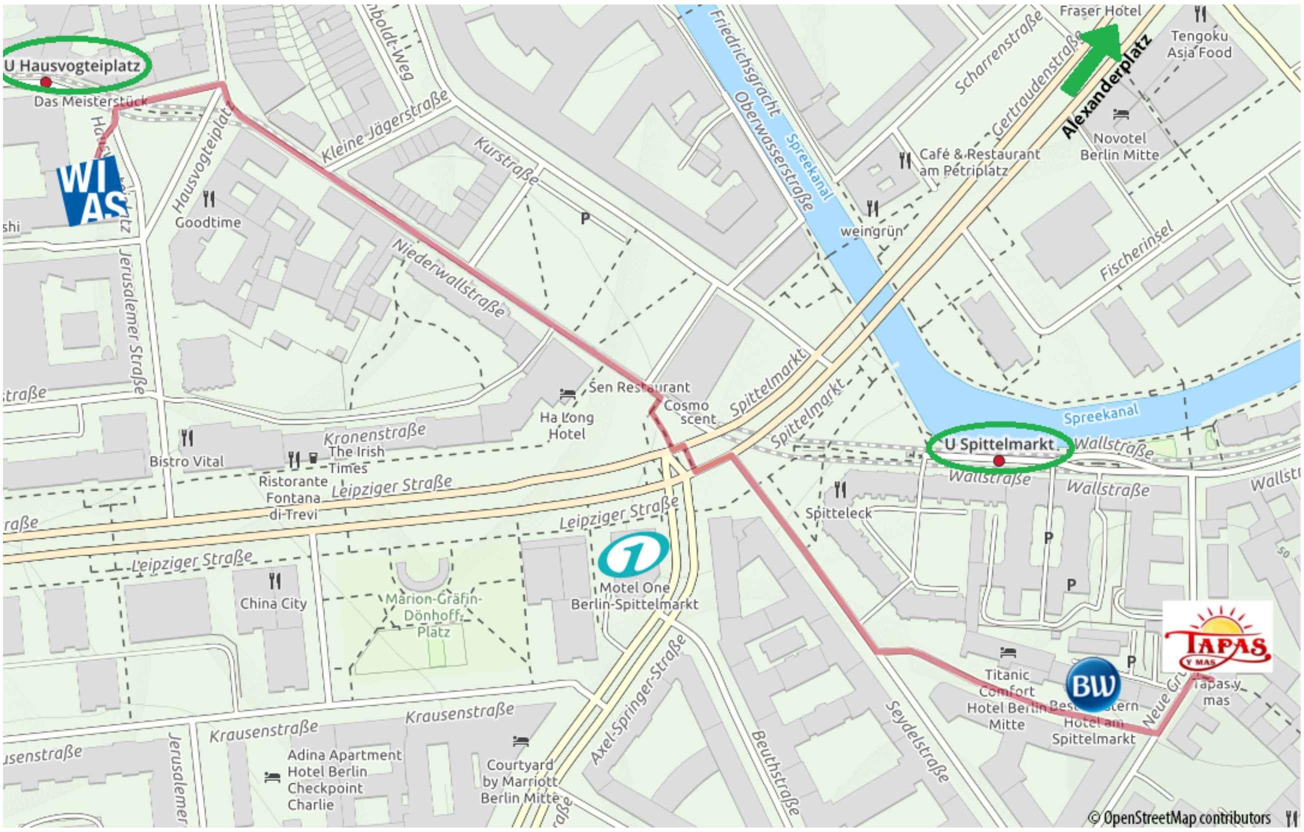
1 Mensa Konzerthaus
2 Bistro Vital
3 Supermarkt
4 Bistro am Gendarmenmarkt
5 The coffee shop
6 Kaffee Einstein
7 Galéries Lafayette
8 Hilton
9 Fontana di Trevi Ristorante
10 Irish Times
11 China-City Restaurant
12 Amici am Gendarmenmarkt
13 Lutter und Wegner
14 Augustiner am Gendarmenmarkt
15 Shan Rahimkan Café
16 Brasserie
17 Löwenbräu
18 Good Time
19 Steinecke
20 Farmer’s Market
21 Springer Building
22 Döner
23 Mc Donalds
24 Subway
25 Borchard
26 Otito Vietnamese Food
27 Chipps
28 Lunch Time
29 Town Bar
30 Leopold’s Kontorhaus

Dinner

The workshop dinner will be held on Thursday, December 6, at 6.30 pm in the restaurant

"Tapas y más"
Neue Grünstraße 17
10179 Berlin-Mitte.

It can be reached from the Weierstrass Institute by feet in max. 15 min.



PROGRAM

Wednesday 05.12.2018		Thursday 06.12.2018		Friday 07.12.2018	
		09:00	Lube	09:00	Barrenechea
		09:35	Merdon	09:35	Nafa
		10:10	Coffee Break	10:10	Coffee Break
		10:40	Schroeder	10:40	Wilbrandt
12:30	Registration	11:15	Knobloch		
13:45	Opening	11:40	Lunch		
14:00	Novo	14:00	Peterseim		
14:35	Kaya	14:35	Bruchhäuser		
15:10	Coffee Break	15:10	Coffee Break		
15:40	Blank	15:40	Sokolov		
16:15	Linke	16:15	Jha		
		18:30	Dinner		