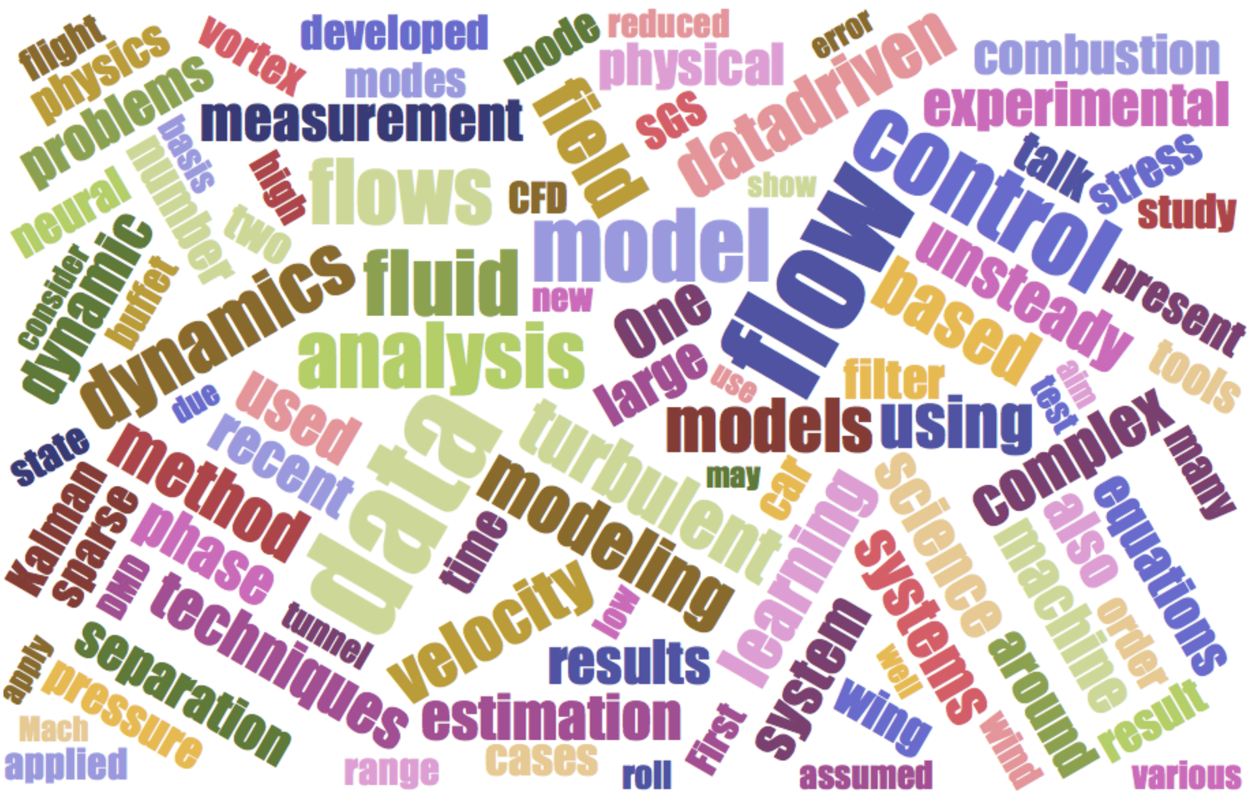
US-Japan Workshop on Bridging Fluid Mechanics and Data Science

March 26-28, 2018

Morito Memorial Hall, Tokyo University of Science, Tokyo



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Website: http://www.eng.famu.fsu.edu/~ktaira/workshop.html

Location:
Morito Memorial Hall
Tokyo University of Science, Tokyo
(http://www.tus.ac.jp/en/campus/kagurazaka.html)

Organizers:
Kunihiko Taira (Florida State University)
Kozo Fujii (Tokyo University of Science)
Anya Jones (University of Maryland)
Koji Fukagata (Keio University)

Target Areas:
Unsteady fluid mechanics
Active flow control
Turbulent flows
Fluid-structure interactions
Advanced experimental diagnostics
Modal decomposition and stability analyses
Data-based methods
Machine learning
Data assimilation
Network science
Reduced-order and sparse modeling
Control and dynamical systems

Abstract:
Over the past two decades, the fluid dynamics community has enjoyed the advancement in computational, experimental, and theoretical techniques to analyze a variety of fluid flows. Developments in computational and experimental hardware, numerical algorithms, and unsteady measurement techniques have enabled not only detailed analysis of flow physics but also initiated cross-talks amongst the various disciplines of fluid mechanics. With these powerful toolsets now available, the fluid dynamics community has started to examine complex flows with high levels of unsteadiness, nonlinearity, and multi-scale dynamics. However, there still exist limitations on how modern analysis techniques can be applied to specific fluid dynamics problems. Theoretical and computational approaches are often limited to relatively simple flows at low Reynolds numbers, while practical applications require extension to more complex unsteady and turbulent flows. Extending the current state of the art in flow analysis to higher Reynolds number flows requires tackling high-dimensional physics and the associated big-data from numerical simulations or experimental measurements. Some of the recent innovations in data science may hold the key to address these issues. The aim of this workshop is to gather fluid dynamics and data science experts from their respective areas and discuss their ongoing progress and challenges in emerging analysis techniques, including data science, computational & theoretical fluid dynamics, and advanced experimental diagnostic methods, that can be shared with others to facilitate breakthroughs as a community. This event will stimulate discussions and collaborations between members of the research communities to identify key areas that can make the largest impact and to offer a vehicle to further strengthen research collaborations across the Pacific.

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DAY 1 Monday, March 26, 2018

09:30-10:00	Registration & Meet and Greet over Coffee
10:00-10:10	Welcoming remarks
10:10-10:20	Overview of the workshop
	Flow Physics I/Experiments (Chair - Jones)
10:20-10:40	Anya Jones (Univ of Maryland)
10:40-11:00	Keisuke Asai (Tohoku Univ)
11:00-11:20	Marios Kotsonis (Delft/Tokyo Univ of Sci)
11:20-11:40	Farrukh Alvi (Florida State Univ)
11:40-12:00	Discussion - Flow Physics I
12:00-13:30	Lunch
	Keynote Presentation I
13:30-14:10	Masato Okada (Univ of Tokyo)
14:10-14:20	Discussion
	Flow Physics II/Computational (Chair - Takeuchi)
14:20-14:40	Shintaro Takeuchi (Osaka Univ)
14:40-15:00	Aiko Yakeno (Tohoku Univ)
15:00-15:20	Kie Okabayashi (Osaka Univ)
15:20-15:35	Discussion - Flow Physics II
15:35-15:50	Coffee Break
	Dynamical Systems (Chair - Taira)
15:50-16:10	Kunihiko Taira (Florida State Univ)
16:10-16:30	Hiroya Nakao (Tokyo Inst of Tech)
16:30-16:50	Hiroshi Gotoda (Tokyo Univ of Sci)
16:50-17:10	Taku Nonomura (Tohoku Univ)
17:10-17:30	Maziar Hemati (Univ of Minnesota)
17:30-18:00	Discussion - Dynamical Systems & Day 1
18:00	Day 1 - Adjourn & Move to Agnes Hotel
19:00-21:00	**Reception at Agnes Hotel** (B1)

DAY 2 Tuesday, March 27, 2018

09:00-09:30	Registration
	Flow Estimation (Chair - Fukagata)
09:30-09:50	Koji Fukagata (Keio Univ)
09:50-10:10	Yosuke Hasegawa (Univ of Tokyo)
10:10-10:30	Takahiro Tsukahara (Tokyo Univ of Science)
10:30-10:50	Coffee Break
10:50-11:10	Shinya Nakano (Inst of Statistical Math)
11:10-11:30	Lionel Mathelin (LIMSI/Univ of Washington)
11:30-11:50	Kazuyuki Nakakita (JAXA)
11:50-12:10	Discussion - Flow Estimation
12:10-13:30	Lunch
	Keynote Presentation II
13:30-14:10	Nathan Kutz (Univ of Washington)
14:10-14:20	Discussion
	Flow Modeling (Chair - Colonius)
14:20-14:40	Tim Colonius (California Inst of Tech)
14:40-15:00	Noriyasu Omata (Univ of Tokyo)
15:00-15:20	Steve Brunton (Univ of Washington)
15:20-15:40	Lou Cattafesta (Florida State Univ)
15:40-16:00	Coffee Break
16:00-16:20	Jeff Eldredge (Univ of California, Los Angeles)
16:20-16:40	Kazuhisa Chiba (Univ of Electro-Comm)
16:40-17:00	Yuji Hattori (Tohoku Univ)
17:00-17:20	Karthik Duraisamy (Univ of Michigan)
17:20-17:50	Discussion - Flow Modeling & Day 2
17:50	Day 2 - Adjourn

DAY 3 Wednesday, March 28, 2018

09:00-09:30	Registration
	Large-Scale Problems/Applications (Chair - Fujii)
09:30-09:50	Kozo Fujii (Tokyo Univ of Sci)
09:50-10:10	Steve Legensky (Intelligent Light)
10:10-10:30	Michio Inoue (Mathworks)
10:30-10:50	Keiko Takahashi (JAMSTEC)
10:50-11:10	Tomoaki Tatsukawa (Tokyo Univ of Sci)
11:10-11:30	Discussion - Large-Scale Problems
11:30-12:00	Wrap-Up Discussions (Next Step? Next Meeting?)
12:00	Day 3 - Adjourn
13:30	Tour of Tokyo

ABSTRACTS

KEYNOTE TALKS

Masato Okada (University of Tokyo)

Sparse Modeling and Data Driven Science

I introduce a project, called the Initiative for High-dimensional Data-Driven Science through Deepening of Sparse Modeling . The aims of this project are to establish a methodology for systematically extracting hypothesis or model from huge amount of high-dimensional data, and to build a core of research system to practice high-dimensional data-driven science in Japan. Through the project, we have become convinced that the three levels pointed out by David Marr give a novel insight into data-driven science, and propose three levels of data-driven science [1].

We consider sparse modeling as a key technology of the data-driven science. The basic notions of sparse modeling (SpM) are as follows. First, high-dimensional data are assumed to have a sparse representation. Second, the number of explanatory variables should be reduced without loss of accuracy. Finally, explanatory variables are selected objectively, and effective models of target phenomena are constructed automatically [1].

In this talk, I explain why an SpM algorithm called LASSO works well, and introduce applications of LASSO in magnetic resonance imaging in medicine, and in astronomical interferometry in astronomy. Next, I introduce an application of Sparsity-promoting Dynamic Mode Decomposition (SpDMD) to coherent-phonon analysis [2]. We showed that SpDMD distinguishes signals of interest from the artifact noise of measurement system.

1. Igarashi, Nagata, Kuwatani, Omori, Nakanishi-Ohno, and Okada, J. Phys. Conf. Ser., 699(1), 012001 (2016).

2. Akai, Murata, Aihara, Tokuda, Iwamitsu, and Okada, Mode-decomposition analysis by SpDMD for coherent phonon signals (I), 2016 Autumn Meeting of The Physical Society of Japan, 14pAL-3 (2016).

Nathan Kutz (University of Washington)

Parametric Reduced Order Model Discovery and Koopman Embeddings

We propose a regression method based upon group sparsity that is capable of discovering parametrized governing reduced order models of a given system by time series measurements. The method balances model complexity and regression accuracy by selecting a parsimonious model via Pareto analysis. This gives a promising new technique for disambiguating governing equations from simple parametric dependencies in physical, biological and engineering systems. Our parametric identification can also be used with a variational autoencoder and deep neural net to discover parametrized Koopman operators of nonlinear systems.

REGULAR TALKS

Farrukh S. Alvi (Florida State University)

High-Fidelity Experimental Data – Two Case Studies

Recent advances in fluid diagnostics have enabled measurement of properties that were until now difficult, if not impossible. In many cases, the spatial and temporal resolution has increased by an order(s) of magnitude. While this has (to some degree) provided insight into the flow physics, the type and sheer volume of data that is produced has created new challenges. These range from the mundane, but practically significant, about where and how to store all this data to the more scientifically relevant as to how one should visualize-process-synthesize these rich data sets to learn as much as we can about the fundamental flow physics - without getting lost. This problem is perhaps not as new to the simulation community but it is one that experimentalists have only recently started tackling. Here we will illustrate this challenge in the context of two experimental studies. The first one involves the flowfield around an Ahmed Body (a generic ground vehicle) where the complex flow topology in the near-wake is feature-rich and highly three-dimensional. This region is interrogated by measuring the velocity/vorticity field using stereoscopic and tomographic PIV. In the second study, we examine the complex, 3D flow field due to a swept shock wave/boundary layer interaction (SBLI) at Mach 2, where the velocity field is documented using stereo-PIV in a conical reference frame. In both cases, we also characterize the flow response to controlled perturbations with the aim of better understanding the pertinent dynamics with the ultimate aim of developing physics based flow control.

Keisuke Asai (Tohoku University)

Recent Research Topics from the Tohoku University's Mars Wind Tunnel

The Tohoku University's Mars Wind Tunnel (MWT) is a unique test facility capable of simulating the condition for Martian atmospheric flight. A supersonic ejector is used to induce high-subsonic flow in the test section at reduced pressure down to one hundredth of atmospheric pressure. The operating envelope ranges the chord Reynolds number from $O(10^3)$ to $O(10^5)$ and Mach number up to about 0.74. Utilizing this unique test capability, various experimental studies have been conducted on the compressibility effect on low-Reynolds-number aerodynamics. In addition to force measurement using a 3-component balance, optical measurement techniques such as Pressure-Sensitive Paint (PSP) and high-speed Schlieren imaging have been employed. This presentation gives an overview of recent research topics from the MWT including the effects of leading-edge serrations on a flat-plate wing, the effects of Mach number on vortex breakdown on a 60-deg delta wing, application of a nanosecond-pulse-driven dielectric barrier discharge plasma actuator (ns-DBDPA) for separation control over a flat-plate wing, and unsteady pressure-field measurement on a circular cylinder using fast-responding PSP. These experiments have shown significant impact of Mach number of low-Reynolds-number flow phenomena.

Steven Brunton (University of Washington)

Data-Driven Modeling and Control of Complex Systems

The ability to discover physical laws and governing equations from data is one of humankind's greatest intellectual achievements. A quantitative understanding of dynamic constraints and balances in nature has facilitated rapid development of knowledge and enabled advanced technology, including aircraft, combustion engines, satellites, and electrical power. There are many more critical data-driven problems, such as understanding cognition from neural recordings, inferring patterns in climate, determining stability of financial markets, predicting and suppressing the spread of disease, and controlling turbulence for greener transportation and energy. With abundant data and elusive laws, data-driven discovery of dynamics will continue to play an increasingly important role in these efforts.

This work develops a general framework to discover the governing equations underlying a dynamical system simply from data measurements, leveraging advances in sparsity-promoting techniques and machine learning. The resulting models are parsimonious, balancing model complexity with descriptive ability while avoiding overfitting. The only assumption about the structure of the model is that there are only a few important terms that govern the dynamics, so that the equations are sparse in the space of possible functions. This perspective, combining dynamical systems with machine learning and sparse sensing, is explored with the overarching goal of real-time closed-loop feedback control of complex systems. Connections to modern Koopman operator theory are also discussed.

Kazuhisa Chiba (University of Electro-Communications)

Unsteady Data Mining for Transonic Buffet Phenomena

The Betti sequence which is one of the topological data analysis has been applied to the time series dataset in which a transonic buffet occurred. In this project, we aim to find temporal and spatial originations of transonic buffet by data analyses, therefore, numerical fluid analysis is performed by unsteady detached eddy simulation which sweeps angle of attack, then datasets are created. In this presentation, as the first trial, we set up six monitoring points in the vicinity where the transonic buffet passes on the wing upper surface; the Betti sequence was applied to the x-directional velocity and the pressure. As a result, on the wing surface, the Betti sequence only responded to the pulse of the physical quantity, as the disturbance of the physical quantities by the separation behind the shockwave and that by the transonic buffet are similar. Other monitoring points should be provided outside the turbulent region.

Louis Cattafesta (Florida State University)
Yang Zhang (Florida State University)
and Larry Ukeiley (University of Florida)

Spectral Analysis Modal Methods (SAMM) for Fluid Dynamics Experiments

Modal methods provide powerful tools for fluid dynamics, encompassing POD, DMD, and resolvent analysis. They provide fundamental understanding of turbulent flows and facilitate modeling and control. However, time- and spatially-resolved data are generally required to obtain unambiguous dynamical information. While feasible in simulations, these tools remain elusive in experiments due to the high cost or limitations of current instrumentation. In the absence of requisite measurements, experimentalists usually resort to variants of stochastic estimation. While popular, these approaches are fraught with potential difficulties and shortcomings, such as inaccuracy, overfitting, and poor interpretability. Here, we discuss the development of a spectral analysis modal method (SAMM) to circumvent these problems and demonstrate its utility in experiments. The proposed method uses measured auto- and cross-correlation functions between approximately spatially (but not time-resolved) flow field data and time- resolved (but not spatially) surface sensor data, such as data routinely used in stochastic estimation. Motivated by the spectral LSE approach of Tinney et al. (2006), we transform these measured functions to the frequency domain using the DFT. In addition, we then apply multiple-input / multiple-output conditional spectral analysis methods and SVD to diagonalize the model and use the inverse DFT to convert back to the time domain.

Tim Colonius
and Andre da Silva (California Institute of Technology)

Data Assimilation for Forecasting Aerodynamic Forces

We adapt techniques used in meteorology, specifically the ensemble Kalman Filter (EnKF) for the purpose of forecasting aerodynamic forces based on a high-dimensional CFD model and limited measurements of pressure on the surface of an airfoil and or velocity at points in the wake. In order to assess the quality of the estimator in detail, an independent numerical simulation is also used as a surrogate for the measurements, to which we add synthetic noise. At least at the low Reynolds numbers considered, we show that a relatively small ensemble of estimators can accurately track the forces when there is no modeling error. Modeling errors are then introduced. We first consider incorrect boundary conditions, in the form of randomized gusting flow over the wing, and show that the state of the estimator can be augmented by parameters associated with the gust (namely freestream velocity) which can in turn be effectively estimated from the sensor data. Next, we consider the more challenging problem of model error, for example by using a coarse grid for the estimator. The resolution error is modeled as a Gaussian-distributed random variable with the mean (bias) and variance to be determined by the estimator. Insights about how to specify the modeling error covariance matrix and its impact on the estimator performance are discussed.

Karthik Duraisamy (University of Michigan)

Physics-Constrained Data-Driven Modeling of Fluid Dynamics Problems

With the proliferation of high-resolution datasets and advances in computing and algorithms over the past decade, data science has risen as a discipline in its own right. Machine learning-driven models have attained spectacular success in commercial applications such as language translation, speech and face recognition, bioinformatics, and advertising. The natural question to ask then is: Can we bypass the traditional ways of intuition/hypothesis-driven model creation and instead use data to generate predictions of fluid dynamics problems, such as turbulent flows? The first part of this talk will discuss the challenges of extending machine learning and data-driven modeling in general to the prediction of complex fluids problems. For instance, regardless of the quantity of interest, there may exist several latent variables that might not be identifiable without a knowledge of the physics; one may not have enough data in all regimes of interest; and the data may be noisy and of variable quality. A pragmatic solution, then, is to blend data with existing physical knowledge and enforce known physical constraints. Thus, one can improve model robustness and consistency with physical laws and address gaps in data. This would constitute a data-augmented physics-based modeling paradigm. Examples of this hybrid paradigm will be highlighted in turbulence and combustion applications.

Jeff Eldredge (University of California, Los Angeles)

Data-Driven Vortex Modeling of Agile Flight

The highly agile flight exhibited by many flying creatures has, for many years, been the promise for the next generation of flight vehicles. However, the reality still falls short, in part because such agility requires flight control strategies that can exploit separated flows rather than avoid them altogether. Recent control strategies based on flapping wings or managed separation over fixed wings have shown promise, but are limited to slow maneuvers because they rely on linearized and/or quasi-steady models of the aerodynamics, only effective at low frequencies or averaged over many flapping cycles. In this presentation, I will report on our recent progress in developing data-driven vortex-based models of separated flows. The premise is to construct a low-degree-of-freedom template model, with the simplest description of the flow that still contains the non-linear vortex-vortex and vortex-wing interactions. The model is then closed in some fashion with empirical data from sensors. In this presentation, I will describe our development of a taxonomy of vortex models that are computationally efficient but still span the range of physical phenomena. Then, I will present a few approaches for closing these models from measured data, using tools from data assimilation, machine learning and optimal control theory. I will demonstrate progress on several canonical problems in two dimensions.

Kozo Fujii (Tokyo University of Science)

Some Issues from Large-Scale High-Fidelity Simulations for Efficient Flow Control

Extracting key features of the flow structure has been an important topic in fluid dynamics for many years. This is especially true for the flow control as the knowledge leads to good design of the control devices. More than 200 hundred cases of iLES simulations were conducted and the analysis with data decompositions and data exploration tools as well as linear stability analysis was applied. The result showed important features behind the flow structures induced by the control devices. However, simple animations of the flow fields still seem to tell us much more than what was obtained from these techniques. This means there remain rooms to develop better "feature probe" of the flow structure. In this talk, the speaker would like to discuss it based on the study of author's group for the last several years on flow separation control.

Koji Fukagata (Keio University)

Optimization and Estimation Problems in Flow Control

For flow control, we often encounter optimization and estimation problems, such as optimization of control parameters and estimation of flow field from available sensor data. In the present talk, we will introduce some examples we encountered in the studies for turbulent friction drag reduction: for instance, feedback control using the streamwise wall-shear information only [1], predetermined control using streamwise traveling wave [2], and passive control using anisotropic compliant surface [3]. We will also introduce our recent attempt to design an effective feedback control law based on the resolvent analysis [4].

1. N. Kasagi, Y. Suzuki, and K. Fukagata, Microelectromechanical system-based feedback control of turbulence for skin friction reduction, Annu. Rev. Fluid Mech. 41, 231-251 (2009).

2. R. Nakanishi, H. Mamori, and K. Fukagata, Relaminarization of turbulent channel flow using traveling wave-like wall deformation, Int. J. Heat Fluid Flow 35, 152-159 (2012).

3. K. Fukagata, S. Kern, P. Chatelain, P. Koumoutsakos, and N. Kasagi, Evolutionary optimization of an anisotropic compliant surface for turbulent friction drag reduction, J. Turbul. 9, N35, 1-17 (2008).

4. S. Nakashima, K. Fukagata, and M. Luhar, Assessment of suboptimal control for turbulent skin friction reduction via resolvent analysis, J. Fluid Mech. 828, 496-526 (2017).

Hiroshi Gotoda and Shogo Murayama (Tokyo University of Science)

Characterization and Detection of Thermoacoustic Combustion Oscillations Based on Statistical Complexity and Complex Networks

Recent progress in the methodologies of time series analysis based on the theory of dynamical systems and complex networks has yielded significant success in the field of combustion physics and science, achieving two main aims: to provide an in-depth physical understanding and interpretation of nonlinear dynamics, and to develop substitute detectors for capturing the onset of combustion instabilities. The promising applicability of the methodologies has been underscored by one of the authors in experimental and numerical studies on a wide spectrum of combustion phenomena including flame front instability induced by swirl/buoyancy coupling (H. Gotoda et al., Phys. Rev. E 95, 022201, 2017), or radioactive heat loss (Kinugawa et al., Chaos 26, 033104, 2016), a buoyancy-induced turbulent fire (K. Takagi et al., Phys. Rev. E 96, 052223, 2017), and thermoacoustic combustion oscillations (H. Gotoda et al., Phys. Rev. E 92, 052906, 2015; H. Gotoda et al., Phys. Rev. Appl. 7, 044027, 2017; H. Kobayashi et al., J. Appl. Phys. 122, 224904, 2017). In this workshop, we present an experimental study on dynamic behavior of flow velocity field during thermoacoustic combustion oscillations from the viewpoints of symbolic dynamics, statistical complexity and complex networks, involving detection of a precursor of thermoacoustic combustion oscillations. The multiscale complexity-entropy causality plane clearly shows the possible presence of two dynamics, noisy periodic oscillations and noisy chaos, in the shear layer region between a vortex breakdown bubble in the wake of the centerbody and the outer recirculation region in the dump plate. Sequential horizontal visibility graph motifs are useful for capturing a precursor of themoacoustic combustion oscillations.

Yosuke Hasegawa (University of Tokyo)

Estimation of a Fully Developed Turbulent Channel Flow with Limited Measurement Data

Estimation of flow and associated scalar fields plays a crucial role in various applications such as weather forecast, identification of pollutant sources in the atmosphere or ocean, deep ocean exploration, development of automated farms etc. However, the highly-nonlinear and multiscale nature of turbulence makes it extremely difficult to estimate a turbulent state from limited and possibly noisy measurement data. In the present talk, we will introduce our recent activities for estimating velocity field in one of canonical turbulent flows, i.e., a fully developed turbulent channel flow. We will apply different techniques such as Kalman filter, an adjoint-based method and linear stochastic estimation. By comparing these results, we will discuss the fundamental difficulty in estimating chaotic turbulent flows.

Yuji Hattori (Tohoku University)

Searching for Turbulence Models for LES by Neural Network

Neural network (NN) is used to construct an improved sub-grid scale (SGS) stress model for large eddy simulation (LES). With the progress of computer resources, it is possible to perform direct numerical simulation (DNS) at moderate Reynolds numbers. DNS results obtained by solving the Navier-Stokes equations are used to calculate correct SGS stress. The correct SGS stress has been used to validate turbulence models. This is called a priori test. Then we apply the data to establish a relation between the correct SGS stress and filtered quantities used in LES. Neural network is used as a tool to establish the relation. We perform DNS of isotropic homogeneous turbulence and train NNs by the result. High correlation coefficients between the correct SGS stress and that estimated by the NNs are obtained. This result shows that NNs can establish a relation without any assumption on the form of relation. In addition, we investigate how the results are improved by the choice of inputs and selection of training data. NNs have great performance when the input is given taking account of the Taylor series of the SGS stress. Same inputs are required in some existing models such as the gradient model and its extensions. The performance is also improved by choosing the training data regarding the deviation in the distribution of SGS stress.

Maziar Hemati (University of Minnesota)

Dynamic Mode Shaping for Feedback Flow Control

Dynamic mode decomposition (DMD) has become a common data-driven systems analysis technique for studying fluid flows. As DMD gains increasing adoption for analyzing numerical and experimental flow data, it stands that our understanding of the role of individual dynamic modes in various fluid flows will become better established. Further, the fluids community has already begun to use insights afforded by DMD to devise open- and closed-loop flow control strategies to enhance fluid dynamic performance. In this talk, we present feedback control strategies that can be used to shape the dynamic modes of a flow in a prescribed manner. We show that dynamic mode shaping strategies can be used to alter or suppress individual dynamic modes, allowing for targeted manipulation of the spatiotemporal dynamics of fluid flows. The talk will provide an overview of dynamic mode shaping, highlight current challenges, and discuss future outlooks, directions, and opportunities in this area.

This material is based upon work supported by the Air Force Office of Scientific Research under award number FA9550-17-1-025.

Michio Inoue (Mathworks Japan)

Big Data and Machine Learning on MATLAB Platform: Practical Guide

Machine learning is quickly becoming a powerful tool for solving complex modeling problems across a broad range of industries. The field of fluid mechanics is not an exception and data-driven modeling has been actively investigated. However, successfully applying machine learning in practice presents challenges. Choosing the algorithms and tuning hyperparameters can consume a large amount of time. As your data, either from experiments or simulation, grow in both size and complexity, it becomes more and more difficult to work with, particularly when the data does not fit into available memory. In this session, we look at different machine learning techniques including deep learning and strategies for handling large amounts of data in MATLAB.

Anya Jones (University of Maryland)

Flow Separation and Wake Dynamics in Unsteady Environments

Highly unsteady aerodynamic environments such as airwakes and gusty winds can result in large force transients and/or flow separation due to interactions with shed vortices and other variations in the relative flow. The evolution and motion of coherent vortices in the flow field around a lifting surface can have a large impact on force transients and recovery. In the current work, we focus on wind gusts and wake interactions that result in changes to the relative flow that are of the same order of magnitude as the freestream flow. This results in a complex, nonlinear problem ill suited to application of classical linear theory. Separated shear layers (from upstream bodies or the wing itself) tend to roll up into coherent vortices that are shed into the wake. At moderate to high Reynolds numbers, these structures are likely the largest scale of unsteadiness present, but smaller scale unsteadiness and turbulence also exist. In ongoing work, the development and motion of large-scale vortices in these flow environments are characterized alongside the smaller scale disturbances in an attempt to identify the flow structures responsible for unsteady airloads in complex flight environments.

Marios Kotsonis (Delft University of Technology & Tokyo University of Science)

Tomographic Particle Image Velocimetry for Transitional Flows

Transitional flows often involve the development, growth and breakdown of boundary layer instabilities. Especially near breakdown, these instabilities often exhibit complex three-dimensional topologies, non-linear behaviour and disparate spatio-temporal scales. These features further complicate the experimental measurement and elucidation of the physics of transition, by conventional techniques. Recent work at TU Delft is based on advanced laser-based flow diagnostics such as tomographic Particle Image Velocimerty. Two examples of transitional flows will be discussed involving later stages of transition in swept wing boundary layers and laminar separation bubbles. Experimental setup, measurements and data post-processing techniques will be reviewed.

Steve Legensky (Intelligent Light)

Extracts and In Situ Workflows to Support Data Modeling

The intersection of Data Science and Fluid Mechanics will require that large volumes of high fidelity CFD results and experimental data be made available to linear algebra techniques. Implementing in situ data extraction workflows that are carefully coupled to reduced order analysis can provide flexibility and productivity as the scope and scale of modelling campaigns grows. A survey of such workflows in use or in development today will be presented along with ideas for future 'in transit' architectures that are better suited to evolving HPC systems.

L. Mathelin, S. Derebail Muralidhar, and B. Podvin (LIMSI/University of Washington)

Data-Driven Estimation of a Turbulent Flow from Wall Sensors

Statistical learning can benefit a lot to inverse and data assimilation problems, either in the form of a data-driven regularizer in conjunction with a model, or in a model-free framework. In this talk, we are concerned with the estimation of a large scalar-valued time-dependent field from a few point-wise measurements. Specifically, we are interested in reconstructing the turbulent velocity flow field from a handful of sensors at the bottom wall in a 3-D turbulent channel flow at a Reynolds number of 580 (based on the wall shear stress τ). Reconstruction of the field from scarce measurements is useful for flow characterization and required for some class of flow control methods (state-based). No governing model is here assumed to be available and we rely on a purely data-driven technique with a training dataset of 20,000 snapshots. The inverse problem is severely ill-posed since the field is of dimension 2×10^7 while there are only about 30 sensors. Further, constraints apply to the flow approximation basis which must obey (nonlinear) observability constraints.

Several possible approaches will be briefly discussed, including kernel techniques for feature learning, sparsity constraints, Koopman analysis, recurrent deep convolutional neural nets, etc. Very preliminary results will be presented with an approach combining kernel and manifold learning.

This is on-going joint-work with S. Derebail Muralidhar and B. Podvin (LIMSI-CNRS, France). SDM is supported by the Paris-Saclay Center for Data Sciences (France).

Kazuyuki Nakakita (Japan Aerospace Exploration Agency)

Development of PSP Measurement and Digital-analog Hybrid Wind Tunnel in JAXA

Two research activities in JAXA are introduced. First is applications of the Pressure-sensitive Paint measurement which is optical and image based pressure measurement technique. Unsteady pressure field behavior from low-speed to supersonic are acquired by this technique. Acquired data are time-series one so that various information such as spectrum, power distribution, coherence, and so on are extracted using FFT analysis. Aeroacoustic field on a wing model in low-speed, transonic buffet on a rocket and a civil transport, and a buzz around a supersonic intake are introduced. Digital-analog Hybrid Wind Tunnel (DAHWIN) is also being developed in JAXA. It is a fusion of experimental and computational fluid dynamics. It is installed in JAXA transonic wind tunnel, and utilized by most of the test campaigns in it. Several example of the fusion of the wind tunnel test results and CFD results by the DARWIN are introduced in presentation.

Shin'ya Nakano (Institute of Statistical Mathematics)

A Non-Parametric Model for Estimating a Divergence-Free Vector Field

Divergence free assumption is useful for modeling the flow velocity distribution in the ionosphere where plasma velocity can be assumed to be orthogonal to a potential electric field. If the divergence of two-dimensional plasma velocity is assumed to be zero, we can consider a stream function yielding the plasma velocity distribution. In order to estimate the two-dimensional flow velocity distribution in the ionosphere, we propose a non-parametric model which expresses the stream function by a linear combination of localized basis functions or kernel functions. Each basis function yields a vector-valued basis function for flow velocity distribution satisfying the divergence-free condition. Thus, we can represent flow velocity distribution by a linear combination of the vector-valued basis functions. We combine this non-parametric model with a state space model and estimate a temporal evolution using a method similar to data assimilation. We are applying the proposed approach to the analysis of the ionospheric radar measurement data and the auroral image processing. Some results of the applications will be demonstrated.

Hiroya Nakao (Tokyo Institute of Technology)

Phase Reduction and Synchronization of Oscillatory Fluid Flows

Rhythmic phenomena in the real world often correspond to limit-cycle oscillations of underlying physical systems. One of the standard methods for analyzing the dynamics of limit-cycle oscillators subjected to weak perturbations is the phase reduction method, which projects the system state onto the phase direction along a limit-cycle trajectory and gives an approximate one-dimensional equation for the phase of the system. The phase reduction method has been successfully applied for analyzing synchronization dynamics of various rhythmic systems. Recently, its relation to Koopman eigenfunctions of the system has also been clarified, providing a new perspective on this classical method. The phase reduction method has been applicable only to finite-dimensional limit-cycle oscillators described by ordinary differential equations, but recent studies have extended its applicability to spatially extended systems described by partial differential equations, such as reaction-diffusion equations describing chemical patterns and fluid equations describing oscillatory flows. In this talk, we present recent developments in the phase reduction method for oscillatory fluid flows. Specifically, we analyze oscillatory thermal convection and oscillatory Karman vortex streets, both of which are limit-cycle solutions of fluid systems. By calculating their phase sensitivities to weak perturbations and deriving phase equations, we analyze synchronization dynamics of these oscillatory flows.

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2 H. Nakao, T. Yanagita & Y. Kawamura, Phys. Rev. X 4, 021032 (2014)

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4 H. Nakao, Contemp. Phys. 57, 188-214 (2016)

Taku Nonomura (Tohoku University)

Kalman Filter Based Dynamic Mode Decomposition

In this presentation, two types of Kalman filter based dynamic mode decomposition are introduced. One is for system identification based on a standard Kalman filter and the other is for both system identification and filtering of variables based on an extended Kalman filter. Both of them are considered to be robust for the strong noise. For the system identification Kalman filter can treat prior noise information as well as transient behavior of the system. On the other hand extended Kalman filter can simultaneously identify the system and filter the observed variables accurately. Formulation of those filters and their performance will be discussed in the presentation.

Kie Okabayashi (Osaka University)

Large-Eddy Simulation for Cavitating Turbulent Flow around a Clark-Y11.7% Hydrofoil

This study is unsteady simulation of cavitating turbulent flow. Cavitation is the phenomenon that the local phase conversion from a liquid phase to a vapor phase occurs because of the pressure drop in the liquid phase. Although a lot of types of cavitation model have been presented, the predictability to cavitating flows was insufficient in previous study. In previous experiment on the cavitating flow around NACA0015 and Clark-Y11.7% hydrofoil, they confirmed that the lift coefficient increases slightly and decrease sharply just after the increase (breakdown) with the decrease of cavitation number (non-dimensional saturated vapor pressure). However, these phenomena were not caught by CFD. We assumed that it may be because previous CFD cannot catch unsteady behavior of cavitation definitely. Therefore, in order to improve the applicability of turbulent cavitating flows, we proposed the application of the one-equation model to the large-eddy simulation (LES) in couple with a cavity source model. The method was applied to turbulent flow with unsteady cavitation around a Clark-Y11.7% hydrofoil. Our results for time-averaged lift and drag were compared with experimental results. In terms on the breakdown properties, our result can catch it as well as an experiment. In addition, slight increase of lift coefficient before breakdown. We investigated the reason why those phenomena were reproduced.

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Noriyasu Omata and Susumu Shirayama (University of Tokyo)

Comparison of unsteady flow fields using a new low-dimensionalization method

To facilitate designs that consider unsteadiness, the properties of unsteady flow fields have been studied. However, the knowledge about unsteady flow fields is not sorted and stored like that of steady solutions, periodic solutions, or flow statistics. One reason for this is that a method capable of comparing and analyzing the spatiotemporal structures of unsteady flow fields has not yet been established. Temporal analyses of unsteady flow fields are often done after the data of the fields are reduced to low-dimensional quantities such as forces acting on objects. Such an approach is disadvantageous as information about the flow field is lost. There are several data-driven low-dimensional representation methods that preserve the information of spatial structure; however, their use is limited due to their linearity. Conversely, methods for comparing spatio-temporal structures are being sought not only in the field of fluid dynamics but also in many other fields. In this study, we propose a method for analyzing the time series data of unsteady flow fields; our method combines low-dimensional representations of spatial structures and the visualization technique originally proposed for dynamic networks. A data-driven nonlinear low-dimensional representation method for unsteady flow fields that preserves its spatial structure is proposed; this method uses a convolutional autoencoder, which is a deep learning technique. We examined the effectiveness of the proposed method by applying it to flow past a two-dimensional airfoil. We showed that the temporal behavior of the flow field's spatial structure could be visualized by the proposed method. Furthermore, we demonstrated that this method is able to compare flow fields that are constructed using different conditions such as different Reynolds numbers and angles of attack.

Kunihiko Taira (Florida State University)

Tackling the Complex Dynamics of Unsteady Flows

Controlling the behavior of flows around air, marine, and ground vehicles can greatly enhance their performance, efficiency, and safety. The challenge in achieving effective control of unsteady flows is caused by their high-dimensionality, strong nonlinearity, and multi-scale properties. The spatial and temporal resolution requirements to fully capture flow physics leads to these flows to be described with a typical dimension of at least a million. Without the reduction of the state variable dimension and extraction of important physics, the application of dynamical systems and control theory for flow control becomes a challenging task. We aim to develop physics-based approaches to model and control complex fluid flows by leveraging high-performance computing, modal analysis methods (POD, DMD, global/parabolized stability, and resolvent analyses), network science, and machine learning. Equipped with these toolsets, we can extract essential dynamics to facilitate the development of sparse and reduced-order models to design flow control techniques for high-dimensional unsteady fluid flows. We discuss some of the challenges and successes our research group has encountered in characterizing, modeling, and controlling unsteady bluff-body wakes and stalled flows over wings.

Keiko Takahashi (JAMSTEC)

TBA

TBA

Shin-taro Takeuchi (Osaka University)

Mechanism of Oscillation and Reversal in Particle-Dispersed Rayleigh-Benard Cells of Laminar Regime

Several oscillation modes in a particle-dispersed Rayleigh-Benard(RB) cell have been reported for finite-sized particles of thermal conductivities higher than the ambient fluid (Takeuchi et al., Int. J. Heat Fluid Flow, vol. 43, 2013). The typical range of the thermal conductivity ratio of the solid to the fluid is between 10^0 and 10^3. In the presentation, we show a linear stability analysis for explaining the oscillation in particle-dispersed RB convection in the low conductivity range (the conductivity ratio around 10^0), while, in a higher thermal conductivity range (the conductivity ratio ranging between 10^2 and 10^3), an angular-momentum model explains that the different time scales for the developments of the velocity and thermal boundary layers determine the oscillation frequency. Also, an attempt of data analysis of the particle-induced reversals of RB cell in a non-linear regime is presented.

We gratefully acknowledge the financial support of Grant-in-Aid (B) No. 17H03174 of the Japan Society for the Promotion of Science (JSPS).

Tomoaki Tatsukawa (Tokyo University of Science)

High-Dimensional Visual Analysis for Simultaneous Design Optimization of Multiple Car Models

The extraction of useful and meaningful information out of high-dimensional data is difficult and complicated. In this study, we present interactive analysis tools developed for high-dimensional engineering data sets. These tools are consist of visualization and data mining techniques, and focusing on finding relation or pattern between parameters. As an application of these tools, simultaneous structure design optimization of multiple car models is considered. Car models applied here are MAZDA CX-5 (SUV car), MAZDA6 wagon (large car), and MAZDA3 hatchback (small car). The objectives are (1) minimization of the total weight of three car models and (2) maximization of the number of common thickness parts. The constraints for each car model consist of crash modes, body torsional stiffnesses, and low-frequency vibration modes. The total number of constraints is 42. The design parameters are the plate thickness of 74 parts of each vehicle model(i.e. 222 design parameters in total). To evaluate crash performances accurately, a finite-element method computation is conducted for each crash mode. A multiobjective evolutionary algorithm is adopted to efficiently find nondominated solutions. As a result of optimization, many designs that outperform the initial design developed by Mazda Motor Corporation are found. In addition, analysis by using developed tools reveals trade-off relation among obtained nondominated solutions.

Takahiro Tsukahara (Tokyo University of Science)

Deep Convolutional Neural Network for Scalar-Source Estimation in Turbulent Flow

Demand is increasing for a quick diffusion-source estimation method to predict the source location and/or emission magnitude based on the downstream information of diffused concentration in the turbulent background. Currently, a substances diffusion in atmosphere/ocean is predicted by forward analytical solutions using conventional CFD method, such as SPEEDI that simulated the radioactive material emitted from a nuclear power plant after the Great East Japan Earthquake in 2011. The emission inversion issue has been also widely examined: backward modelling techniques have been developed for applications to an extensive accident, and meteorological and oceanographic issues. However, those forward and backward simulations should encounter the issue of immediacy in the source estimation after an accident. In this study, we propose a new approach for quick identification of an unknown source location, using deep convolutional neural networks: from a photo image of instantaneous concentration distribution, the trained network allows us to estimate immediately the distance from the source. A large amount of training data is required for the deep-learning algorithm to achieve outstanding performance. To prepare the training data, we used PLIF (planar laser-induced fluorescence) images of water-channel experiment. The practicability of the proposed approach is verified in the location identification of the single-point dye source in the turbulent channel flow.

Aiko Yakeno (Tohoku University)

Turbulence Growth Dependency on Excitation Frequency by Local Body-Force around 2D Hump

We investigated details of wake vortex dynamics to cause turbulence increase and early flow-reattachment under excitation forcing of a plasma actuator setting around a 2D hump numerically. The local body-force was homogeneous in the spanwise direction. That actuation causes two-dimensional roll vortices and other three-dimensional motions such like rib structure is generated in downstream. These characteristics depend on the excitation frequency.

We tried to discuss multi-scaled vortices separately with considering the temporal phase-averaged statistics of the excitation frequency and others, those are dominated by roll vortices and rib structure between rolls, respectively. It was found that the maximum value of non-periodic fluctuation in downstream correlated with flow-reattachment performance more than that of periodic fluctuation of roll vortices. The amplitude becomes large around separation position in early reattachment cases. It seems that the non-periodic fluctuation due to three-dimensional rib structure is the key factor for the separation control.

The spacial growth rates of peak values in the wall-normal direction are same for high frequency cases, K-H instability modes, however not true for low frequency cases. In high frequency cases, amplitude in the early state of separation plays a significant rule to increase it in downstream. In low frequency cases, it is important that two-dimensional roll vortex generation much happens, which is associated with increase of the three-dimensional rib-structure.

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US-Japan Workshop on Bridging Fluid Mechanics and Data Science

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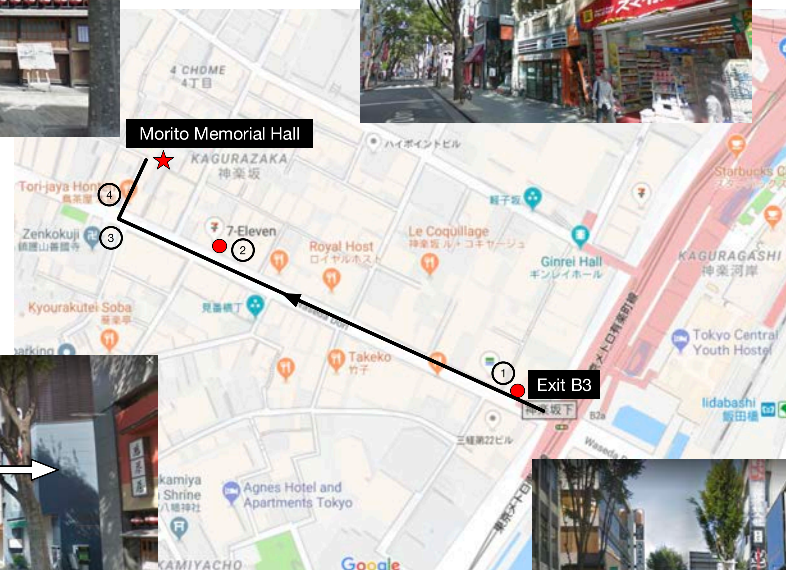
Guide map from Iidabashi Station to Morito Memorial Hall (Workshop Location)

Morito Memorial Hall (Entrance)

4. Shown is the entrance to the small road that leads to the Morito Memorial Hall at the end.

2. After walking around 200 meters, you will see a 7-Eleven (convenience store) on the right side of the road. Keep walking.



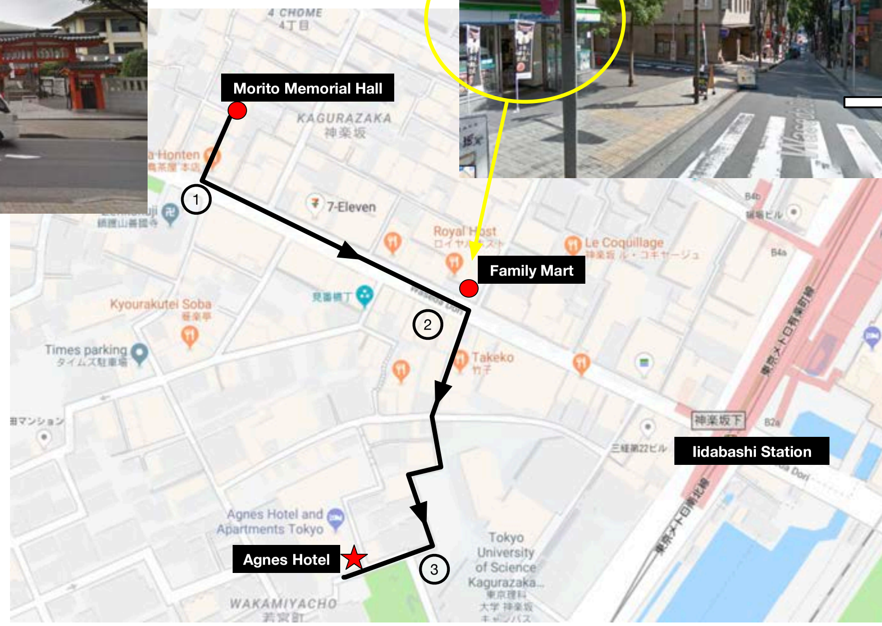
3. After another 50 meters, from the 7-Eleven (2), you will see a Japanese shrine on the left side of the road. Take the small road OPPOSITE to the shrine.

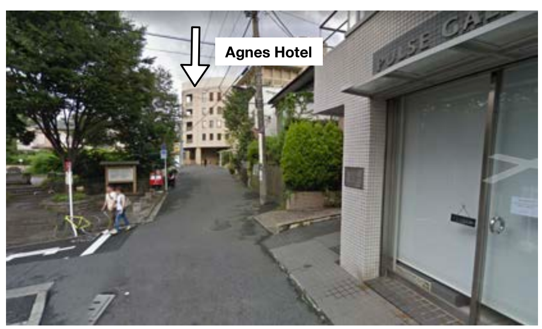
1. Exit Iidabashi Station (use B3 exit) then turn RIGHT. Follow the main street in this direction (uphill).

Guide map from Morito Memorial Hall to Agnes Hotel (Reception)

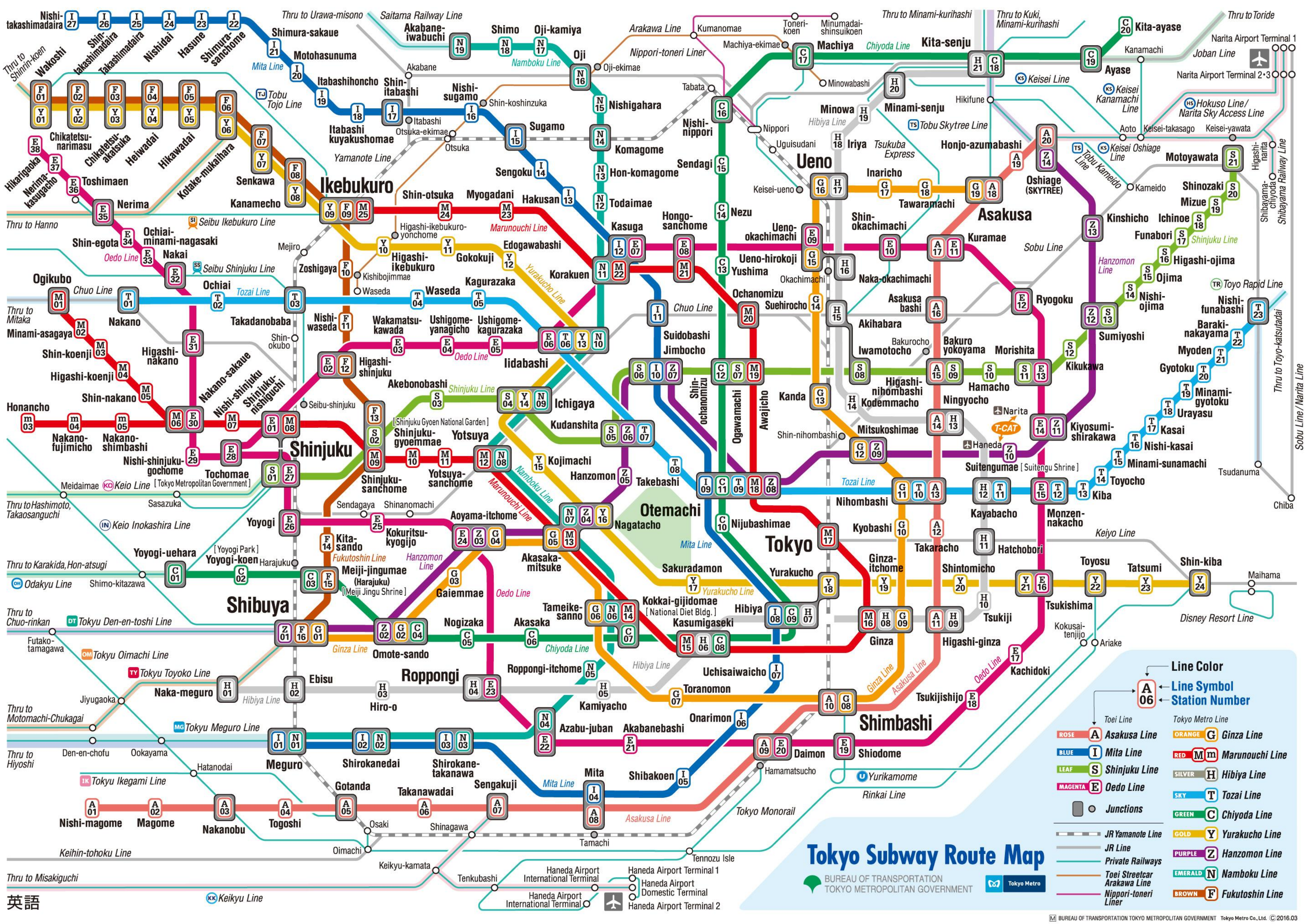
1. Leave Morito Memorial Hall, walk to the main street: Waseda Dori. You will see a Japanese shrine. Turn LEFT here.

2. Walk until you see this intersection. Look for the Family Mart on the left. Take a RIGHT turn at this crosswalk.





3. Follow the small road (no turns to be made at intersections). When you see this scene, Agnes hotel is right in front of you.


Tokyo Subway Route Map
BUREAU OF TRANSPORTATION
TOKYO METROPOLITAN GOVERNMENT
Tokyo Metro
Line Color
Line Symbol
Station Number
Toei Line
Tokyo Metro Line
Asakusa Line
Mita Line
Shinjuku Line
Oedo Line
Junctions
Ginza Line
Marunouchi Line
Hibiya Line
Tozai Line
Chiyoda Line
Yurakucho Line
Hanzomon Line
Namboku Line
Fukutoshin Line
JR Yamanote Line
JR Line
Private Railways
Toei Streetcar Arakawa Line
Nippori-toneri Liner
Ikebukuro
Shinjuku
Shibuya
Ueno
Asakusa
Otemachi
Tokyo
Shimbashi
Roppongi
Nishi-takashimadaira
Wakoshi
Ogikubo
Honancho
Nakano
Meguro
Oshiage (SKYTREE)
Kita-senju
Kita-ayase
Ayase
Nishi-funabashi
Motoyawata
Shin-kiba
Nishi-magome
Narita Airport Terminal 1
Narita Airport Terminal 2·3
Haneda Airport Terminal 1
Haneda Airport Terminal 2
Haneda Airport International Terminal
Haneda Airport Domestic Terminal
Thru to Urawa-misono
Thru to Minami-kurihashi
Thru to Kuki, Minami-kurihashi
Thru to Toride
Thru to Shinrin-koen
Thru to Hanno
Thru to Mitaka
Thru to Hashimoto, Takaosanguchi
Thru to Karakida, Hon-atsugi
Thru to Chuo-rinkan
Thru to Motomachi-Chukagai
Thru to Hiyoshi
Thru to Misakiguchi
Thru to Toyo-katsutadai
英語
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