2005 Program Overview
Chess SUPERB-IT

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Overview

This Document

This projects description document provides an introductory look at our goals and objectives for the summer, and describes in some depth the technical topics which the students and mentors will investigate through research. As a student reading this document, please find your name and mentor's name under a project, read that chapter, and follow the instructions given in the *Preliminary Tasks* subsection, which will give you a good head start to having an excellent research achievement by the end of the summer.

As a general rule, project topics are fairly fixed—meaning that we spent a large amount of time devising topics that looked like they would intersect on some level with,

- the goals of Chess,
- student background, in terms of classes and performance,
- student aptitude, as we guessed from resumés,
- student preferences listed in the SUPERB application,
- mentor background and interests, and
- overall contribution to a cohesive project.

It should be noted, though, that these constraints were not necessarily applied in that order. When students arrive, or if need be prior to their arrival, we will refine their projects based on their feedback and any incoming research goals, to hope to align them for increased performance throughout the summer.

In the meantime, please do not hesitate to contact the project leader, Dr. Jonathan Sprinkle, or your mentor, with any questions about the program, your project, or what you can do to prepare for what we hope is the most exciting and interesting summer you have ever had.

Jonathan Sprinkle, Ph.D.
May 26, 2005
Berkeley, CA

About the programs

Chess

The Center for Hybrid and Embedded Software Systems (Chess[1]) is aimed at developing model-based and tool-supported design methodologies for real-time fault tolerant software on heterogeneous distributed platforms. We are bridging the gap between computer science and systems science by developing the foundations of a modern systems science that is simultaneously computational and physical. This represents a major departure from the current, separated structure of computer science (CS), computer engineering (CE), and electrical engineering (EE): it reintegrates information and physical sciences. The center is funded in part by an Information Technology Research (ITR) project from the National Science Foundation (NSF). It operates cooperatively with the Institute for Software Integrated Systems (ISIS[2]) at Vanderbilt University, and the Department of Mathematical Sciences at the University of Memphis.

SUPERB-IT—2005

The Center for Hybrid and Embedded Software Systems is proud to sponsor six undergraduate students from diverse backgrounds and cultures to participate in the Summer Undergraduate Program in Engineering Research at Berkeley (SUPERB-IT). These students will interact with individual mentors throughout the summer, and perform research and supporting activities in the area of hybrid and embedded systems.

Electrical Engineering & Computer Sciences (EECS)—SUPERB-IT

The Summer Undergraduate Program in Engineering Research at Berkeley–Information Technology (SUPERB–IT) in the Electrical Engineering and Computer Sciences (EECS) Department offers a group of talented undergraduate engineering students the opportunity to gain research experience. The programSs objective is to is to provide research opportunities in engineering to students who have been historically underrepresented in the field for reasons of social, cultural, educational or economic barriers, by affirming studentsS motivation for graduate study and strengthening their qualifications.

From the College

The goal of the Summer Undergraduate Program in Engineering Research at Berkeley (SUPERB) is to provide research opportunities in engineering to students who have been historically underrepresented in the field for reasons of social, cultural, educational or economic barriers. The program provides students with the opportunity to gain research experience by participating in research projects with engineering faculty and graduate students. Upon completion of this program students will be better prepared and motivated to attend graduate school.

[1] http://chess.eecs.berkeley.edu/
[2] http://www.isis.vanderbilt.edu/

Part I

Goals & Objectives

Chapter 1

Cohesive Project Vision

The SUPERB program is dedicated to providing undergraduate students with the opportunities and experiences of research. At Chess, where our research goals are at the intersection of traditional Electrical Engineering and Computer Science, this includes a wide variety of possible topics including robotics, systems theory, programming, image processing, algorithm development, simulation, and good old mathematics.

More importantly, the Chess philosophy is that new developments in traditional research areas will emerge from interdisciplinary cooperation between Electrical Engineering and Computer Science researchers. To reflect this, and the wide array of possible topics, we have chosen for the 2005 SUPERB program a set of projects which intersect in some areas, and are independent in others, and will allow for inter-student cooperation to devise new solutions to unsolved problems.

It is important to note that several projects fit into more than one category. We believe this is typical of research at Berkeley, and will be reflective of research everyone in the future. Our goal is to use this as a benefit for the student over the summer, where they will learn how to think in terms of multiple goals at once, and achieve results that can be interesting to experts in more than one field.

1.1 Hybrid Systems

Hybrid systems are systems that may be described using discrete states in which continuous time dynamics govern the laws of behavior. Many of the world's experts on hybrid systems have been educated at Berkeley, and faculty members of Chess are considered authoritative on the subject.

Ongoing research at Berkeley in hybrid systems involves the analysis of those systems (under Prof. Sastry), and simulation of those systems (under Prof. Lee). A tool which will be used is HyVisual (see `http://ptolemy.eecs.berkeley.edu/hyvisual`), based on the Ptolemy II platform (see `http://ptolemy.eecs.berkeley.edu/`). Involved projects will be Project 6, Project 5, and Project 1.

1.2 Sensor Networks

Security, communication, and data gathering are all interests of the research area of sensor networks. Sensor networks are distributed, collective or communicated nodes which gather information and either forward it on to a processing station, or do some local filtering prior to forwarding information.

Development of theory and simulation of sensor networks is an ongoing thrust at Berkeley, involving Prof. Lee and Prof. Sastry. One tool under development at Berkeley is VisualSense (see `http://ptolemy.eecs.berkeley.edu/visualsense/`), based on the Ptolemy II platform (see `http://ptolemy.eecs.berkeley.edu/`). Involved projects will include Project 2, and perhaps Project 4, and should include the large camera testbed at Cory Hall.

1.3 Computer Vision

The field of computer vision is a burgeoning research area at the intersection of image processing, information theory, and computer science. At heart, computer vision is about using cameras and images for more than just image information, but also information about the environment, control of systems through a vision feedback controller, or other exciting and complex methods.

At Berkeley, experts in computer vision are working in the area of biomedical systems, surveillence networks, target tracking, and flight control through vision. On the 3rd floor of Cory Hall, we have installed a larget networked array of cameras which provide nearly full coverage of the entire floor, for the purposes of testing algorithms and techniques for tracking objects, recognition, etc. At the core, we will try to use this network as an array of *sensors*, instead of just an array of *cameras*. This will allow us to work within the domain of sensor networks, and will result in collaboration with Project 3.

1.4 VLSI Design

Embedded systems are systems where the computer is an integral part of the system. One way in which this is obtained is to create computers which are specific to the particular task, and are so-called "System on Chip" (SoC) computers.

In order to create these systems, however, a large amount of knowledge must exist for the domain in which the computer will be operating. Prof. Alberto Sangiovanni-Vincentelli of UC Berkeley is an industry-recognized leader in embedded systems, and has been at the forefront of the design of these systems for decades. The project will likely be a development of systems for networking, including perhaps routers, or optimization of topology of the design. Possibilities for overlap include Project 3.

1.5 Simulation

An age-old mantra of electronics is "sand is cheaper than glass"—meaning that a resistor was much cheaper than a diode. In the broad discipline of engineering "simulation is cheaper than sand"—but only if your simulation is valid.

Various projects will use simulation as an integral part of their design, or in the case of Project 5 as the science of the project. The simulation will include hybrid systems, networks, camera data, chip performance, and bipedal walkers. By the time the summer is over, each student will have some confidence in how to use simulation as a piece of the design flow for any kind of system.

Chapter 2

Cross-cutting Experiences

In addition to the science of research, we will also expose students to the reporting aspects of research. These include the techniques used for writing papers, technical skills such as the use of LaTeX, and the importance of having a stock version of what exactly it is you are working on. A brief description of some of these experiences are given below.

2.1 LaTeX template design

One student will use newfound knowledge of LaTeX paper creation to design a template which each student will use for their final paper writing.

2.2 Poster design

One student will use existing poster designs, and input from mentors regarding the philosophy behind a poster, to design a template which each student will use (or choose from) for their final presentation.

2.3 Concurrent Versioning System (CVS)

The technical craft of writing software, or any collaborative project, eventually runs into the problem of versioning, and multi-user problems such as overwriting, or file locking. CVS is a technology that solves some of these problems, and students will use it for their code, reporting, and website duties while participating in SUPERB.

2.4 Reading group participation

All students will participate in a hybrid systems reading group that will meet weekly during their tenure in SUPERB-IT. The papers and philosophy toward exploration of the body of research will enhance student understanding of why it is important to publish, and also why it is important to write well when publishing. Individual sessions will be led by some of the students, and will intersect with reading they performed for their own research.

2.5 Website update

The CHESS website is easily configurable and updateable via CVS and other authoring techniques. Students will keep the website updated to reflect weekly presentations, reading group discussions, the resources used by students for paper-writing and poster creation, and also social interactions ongoing in the SUPERB-IT program.

Part II

Projects

Project 1

A bipedal descent walker: model, simulation, and analsysis

Researcher: Simon Ng[1]
Mentor: Haiyang Zheng[2]

1.1 Overview

The purpose of this project is to model and simulate a passive bipedal walker introduced by Tad McGeer [1] [2] in HyVisual [3]. The interesting part about the bipedal walker is that it can walk down a slight slope without any extra energy provided except the potential energy induced by the gravity force. There is no extra control input provided either.

A few good online references are listed below:

1. The Biorobotics and Locomotion Lab at Cornell University. The URL is `http://ruina.tam.cornell.edu/research/topics/locomotion_and_robotics/overview.htm`.
2. The Passive Dynamic Walking project at University of Michigan. The URL is `http://www-personal.engin.umich.edu/~artkuo/Passive_Walk/passive_walking.html`.

1.2 Technical Tasks

The first step is to understand the dynamics of the bipedal walker, including the fundamentals introduced in the papers of Tad McGeer and the stabilization problem discussed by Arthur D. Kuo in [4].

The second step is to implement some existing algorithms from the above references to model and simulate bipedal walkers in HyVisual. Along with this, the student will provide methods for animating the simulation results. Graphic animation is desired to get intuitive understanding of the dynamics and to reason about the correctness of models.

The last step is to expand upon these algorithms, e.g., to add a double support phase for the bipedal walker [3].

[1] Simon Ng is a rising senior at Michigan State University, majoring in Computer Science.

[2] Haiyang Zheng is a Ph.D. student at the EECS department of University of California, Berkeley. His research interest is about theory, modeling, and simulation of hybrid systems.

[3] This step is closely related to Project 6 by Robert D. Gregg and Aaron D. Ames.

1.2.1 Specification of the model

The model of a bipedal walker can be specified as a hybrid system (see Project 6). Given this, HyVisual is an excellent simulation environment, and analytical methods for hybrid systems will be extremely relevant.

1.2.2 Simulation using HyVisual

The student will use HyVisual to perform the modeling and simulation of the bipedal walker.

HyVisual is a visual modeler that supports construction of hierarchical hybrid systems, which are systems with continuous-time dynamics, discrete events, and discrete mode changes. It uses a block-diagram representation of ordinary differential equations (ODEs) to define continuous dynamics. It uses a bubble-and-arc diagram representation of finite state machines to define discrete behavior.

A good tutorial of how to use HyVisual is described in "HyVisual: A Hybrid System Visual Modeler" (see `http://ptolemy.eecs.berkeley.edu/publications/papers/04/hyvisual`)[3]. The underlying operational semantics are given in "Operational Semantics of Hybrid Systems", which may be found at `http://ptolemy.eecs.berkeley.edu/publications/papers/05/OperationalSemantics/`[5].

1.2.3 Analysis

This will interface tightly with Project 6, analysis of hybrid systems. The students and mentors will develop working relationships which will enable collaboration.

1.3 Preparatory Tasks

Before arriving, the following tasks should be done by the student:

1. Go through the above two online references.
2. Read the introduction part of the HyVisual manual.
3. Time permitting, do some experimentation with HyVisual demonstrations.

Bibliography

[1] T. McGeer, "Passive dynamic walking (two-legged machines)," *International Journal of Robotics Research*, vol. 9, no. 2, pp. 62–82, 1990, uSA. English Journal Paper.

[2] ——, "Passive walking with knees," in *Proceedings 1990 IEEE International Conference on Robotics and Automation (Cat. No.90CH2876-1). IEEE Comput. Soc. Press. 1990, pp.1640-5 vol.3. Los Alamitos, CA, USA.*, 1990, cincinnati, OH, USA. IEEE. 13-18 May 1990. English Conference Paper.

[3] A. Cataldo, C. Hylands, E. A. Lee, J. Liu, X. Liu, S. Neuendorffer, and H. Zheng, "Hyvisual: A hybrid system visual modeler, Tech. Rep. Technical Memorandum UCB/ERL M03/30, 2003.

[4] A. D. Kuo, "Stabilization of lateral motion in passive dynamic walking," *International Journal of Robotics Research*, vol. 18, no. 9, pp. 917–30, 1999, publisher: Sage Publications, USA. English Journal Paper.

[5] E. A. Lee and H. Zheng, "Operational semantics of hybrid systems," in *Proceedings of Hybrid Systems: Computation and Control, 8th International Workshop, HSCC 2005*, ser. Lecture Notes in Computer Science, M. Morari and L. Thiele, Eds., vol. 3414. Springer-Verlag, Mar. 2005.

Project 2

Learning Dynamics and Tracking

Researcher: Lana Carnal[1]
Mentor: Parvez Ahammad[2]

The idea of a set-up of multiple sensors working together to accomplish various tasks is nothing new. Today a variety of good quality sensors are easily affordable. This is true with visual sensors like cameras too. Moreover, with the affordability of computational power, it is now practical to imagine visual sensors with some computational power which can do some basic information processing at the front end. While the networks of wireless motion sensors, temperature sensors and other kinds of sensors have lead to new directions in research, not much of the work has been extended to networks of visual sensors or cameras in particular.

We want to take a fresh look at the idea of networked cameras from the points of view of computational vision and information theory. We argue that creating a large network of high-bandwidth sensors such as cameras is a challenging problem - and needs to be dealt with in a separate manner. There are a few significant reasons for this - such as, possibility of utilizing spatial correlation across the sensors, problems pertaining to very high data rates across the network, challenges in representation of visual data for efficient processing and trade-offs between central Vs. distributed computation to achieve the objectives.

2.1 Overview

Our focus is primarily in the situations where large amount of activity is going on in the observed space spanned by the network of cameras. Even though significant body of research exists in tracking people from one or two camera views, a co-ordinated system of cameras to systematically analyze crowd behavior and individual motion patterns of interesting objects is relatively under-studied. We hope to develop algorithms that can effectively handle multiple views, occlusion issues, large baseline between the cameras and the network scalability issues. To achieve this end, we have built a network of cameras in the third floor of Cory Hall that consists of both directional and omnidirectional cameras which span the overall space of the third floor hallways. There is a variable overlap between the space observed by different cameras and the resolutions of directional cameras differ from the resolutions of the omnidirectional cameras.

In this project, we will focus on observing the space spanned by a network of cameras and learning the dynamics of the objects or people moving in this space. There are interesting challenges posed in this task due to reflections and clutter in the background, partial overlap between the different cameras, difference in resolutions, constraints on bandwidth, and the significant variability in shape from one person to another. Our algorithm must be robust to these variations, and infer the dynamics of the objects moving in the observation space, to help provide a coherent

[1] Lana Carnal is a rising junior at the University of Tennesse, Knoxville, majoring in Electrical Engineering.

[2] Parvez Ahammad is a third year PhD student at the University of California, Berkeley, in the Department of Electrical Engineering and Computer Sciences, working with Prof. S. Shankar Sastry.

overall description of the object movement. The learned dynamics will be used as an input to the relevant modeling packages (VisualSense) to obtain a coherent view of the object movement across the network.

2.2 Technical Tasks

Understanding the basics of Image Processing and Computer Vision background material that will help with achieving the project objectives (or willingness to learn), basic understanding of algorithms, Programming (MATLAB, C), Evaluation and characterization of performance of the algorithms developed during the project period.

2.3 Preparatory Tasks

Before arriving, the following tasks should be done by the student:

1. Review your programming basics, and familiarize yourself with Matlab.
2. Acquire a copy of a good image processing book ([1]), and look through.
3. Contact the mentor to give an idea of what you think you can or can't do in this project framework.
4. If anything is not clear, or you want specific paper references, contact the mentor.

Bibliography

[1] R. C. Gonzalez and R. E. Woods, *Digital Image Processing*. Boston, MA, USA: Addison-Wesley Longman Publishing Co., Inc., 2001.

Project 3

Modeling Distributed Camera Networks with VisualSense

Researcher: Murphy Gant[1]
Mentor: Yang Zhao[2]

The goal of this project is to model camera networks in VisualSense to simulate the dynamics of moving objects and tracking them in a field. We will collaborate with Lana Carnal and Parvez Ahammad who work on Project 2.

3.1 Overview

Camera networks, as one kind of sensor networks, are attracting for environment monitoring and object tracking. The cameras are supposed to be very cheap, with some computation ability for basic information processing, and with some communication ability for coordination. How to effectively use the computation power on each camera and have them collaborate to monitor the motion of an object is a challenge problem. Project 2 will focus on developing algorithms that can effectively handle multiple views and learning the dynamics of the objects or people moving in the field. We will implement and simulate these algorithms in VisualSense and help to tune them.

VisualSense is a modeling and simulation framework for wireless and sensor networks that builds on and leverages Ptolemy II [1]. Modeling of wireless networks requires sophisticated modeling of communication channels, sensors, networking protocols, localization strategies, energy consumption in sensor nodes, etc. This modeling framework is designed to support a component-based construction of such models. The software architecture consists of a set of base classes for defining channels and sensor nodes, a library of subclasses that provide certain specific channel models and node models, and an extensible visualization framework. Custom nodes can be defined by subclassing the base classes and defining the behavior in Java or by creating composite models using any of several Ptolemy II modeling environments. Custom channels can be defined by subclassing the WirelessChannel base class and by attaching functionality defined in Ptolemy II models. The algorithms mentioned above will be implemented as some Java classes, and be used to customize a sensor node.

3.2 Technical Tasks

Understanding how VisualSense works, basic understanding of algorithms, Programming with JAVA.

[1] Murphy Gant is a rising junior at Diablo Valley College, majoring in Electrical Engineering and Computer Science.

[2] Yang Zhao is a graduate student in the Department of Electrical Engineering and Computer Sciences at University of California, Berkeley, working with Professor Edward A. Lee. Her research interests include reliable distributed systems, sensor networks, and real-time systems.

3.3 Preparatory Tasks

Before arriving, the following tasks should be done by the student:

1. Review your programming basics, and familiarize yourself with JAVA.
2. Learn VisualSense by looking at [2] and [3].

Bibliography

[1] C. Brooks, E. A. Lee, X. Liu, S. Neuendorffer, Y. Zhao, and H. Zheng, "Heterogeneous concurrent modeling and design in java: Volume 1: Introduction to ptolemy ii," University of California, Tech. Rep. Technical Memorandum UCB/ERL M04/27, July 29 2004. [Online]. Available: http://ptolemy.eecs.berkeley.edu/publications/papers/04/ptIIDesignIntro/

[2] P. Baldwin, S. Kohli, E. A. Lee, X. Liu, and Y. Zhao, "Modeling of sensor nets in ptolemy ii," in *In Proc. of Information Processing in Sensor Networks, (IPSN)*, April 2004.

[3] ——, "Visualsense: Visual modeling for wireless and sensor network systems," University of California, Tech. Rep. Technical Memorandum UCB/ERL M04/08, April 23 2004. [Online]. Available: http://ptolemy.eecs.berkeley.edu/papers/04/VisualSenseERLMemo0408/

Project 4

On-chip networks

Researcher: Reinaldo Romero [1]
Mentor: Alessandro Pinto[2]

4.1 Overview

Design of complex systems is very challenging. The main reason resides in their distributed nature at all scales. The fundamental assumption that communication among agents takes zero time does not hold in many of this systems. Even on a chip, where distances are limited to millimeters, sending information from one corner of the chip to the other is estimated to take several clock cycles [1]. Designing a good communication infrastructure that is able to guarantee end-to-end quality of service becomes then crucial.

Communicating devices have also very tight constraints especially in terms of power consumption. Hand-held devices, or tiny sensor nodes that communicate wirelessly do not have much power to waste. Constraints on power consumption of an electronic device translates on constraints on the power consumption of its components that are chips and processors. Since the communication infrastructure accounts for a considerable part of the chip power consumption, it has to be optimized.

The first step in the communication architecture design is to find the right network topology [2, 3, 4, 5, 6, 7]. Topology synthesizers build networks by instanciating, configuring and interconnecting communication components from a library. The objective is to minimize the total cost of the network which is the sum of the instanciated components. It is extremely important to provide the synthesizer with information about *costs and performances of communication components*.

After the topology has been chosen, the second step is to come up with a *protocol* that can best utilize the network and guarantees the required quality of service.

The synthesis algorithm can be run off-line in the case of static networks. If agents are mobile and the communication requirements can change over time, *adaptive* synthesis algorithms have to be developed and *distributed* on the networks agents.

Based on this observations, three projects are proposed:

- a hardware oriented project whose goal is to build and simulate components for on-chip networks.
- A protocol synthesis project whose goal is to start from a set of traffic patterns and constraints and automatically bin the patterns in classes of services and configure a network to satisfy end-to-end constraints.
- A more high level project whose goal is to develop a distributed algorithm for on-line topology optimization.

[1]Reinaldo Romero is a rising senior at Penn State University, majoring in Electrical Engineering.
[2]Alessandro Pinto is a graduate student at University of California at Berkeley majoring in Computer-Aided Design

4.2 Technical Tasks

4.2.1 On-chip Links and Routers Characterization

This project requires to design and characterize different types of links and routers. Previous works are based on models and simulation [8, 9]. The following is a list of subtasks:

- Verilog description of input-queued, output-queued, input/output-queued routers.
- Synthesis and technology mapping of the Verilog description to obtain a gate level description.
- Simulation of the synthesized router to obtain a profile of energy consumption and input-output delay.
- Simulation of optimally buffered on-chip wires to obtain energy consumption and delay.
- (If there is time) Simulation of an entire network of links and routers.

4.2.2 OCP-IP protocol configuration for on-chip networks

The OCP-IP [10] is an international partnership that is developing the Open Core Protocol, a standard protocol for on-chip communication. The protocol has many transaction types and many parameters that can be configured. The project requires to generate a configuration of the protocol depending on the end-to-end delay requirement of each pair of communicating agents. The following is a list of subtask:

- given the protocol specification, define a set of parameters for routers and networks interfaces.
- Given the network topology and the delay constraints, define classes of service and priorities.
- Write an automatic tool that configures each component in the network.

4.3 Preparatory Tasks

As a preparatory task the student should read the papers in the bibliography.

Bibliography

[1] M. Horowitz, R. Ho, and K. Mai, "The future of wires," 1999. [Online]. Available: citeseer.ist.psu.edu/horowitz99future.html

[2] T. Ahonen, D. A. Siguenza-Tortosa, H. Bin, and J. Nurmi, "Topology optimization for application-specific networks-on-chip," in *Proc. of the 2004 Int. Workshop on System level interconnect prediction*. New York, NY, USA: ACM Press, 2004, pp. 53–60.

[3] S. Murali and G. D. Micheli, "Sunmap: a tool for automatic topology selection and generation for nocs," in *Proc. of the 41st annual conference on Design automation*. New York, NY, USA: ACM Press, 2004, pp. 914–919.

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[5] K. Srinivasan, K. S. Chatha, and G. Konjevod, "Linear programming based techniques for synthesis of network-on-chip architectures." in *ICCD*, 2004, pp. 422–429.

[6] A. Pinto, L. P. Carloni, and A. L. Sangiovanni-Vincentelli, "Constraint-driven communication synthesis," in *DAC '02: Proceedings of the 39th conference on Design automation*. New York, NY, USA: ACM Press, 2002, pp. 783–788.

[7] ——, "Efficient synthesis of networks on chip," in *21st International Conference on Computer Design*, October 2003, p. 5.

[8] T. T. Ye, G. D. Micheli, and L. Benini, "Analysis of power consumption on switch fabrics in network routers," in *Proc. of the 39th conference on Design automation*. New York, NY, USA: ACM Press, 2002, pp. 524–529.

[9] H.-S. Wang, X. Zhu, L.-S. Peh, and S. Malik, "Orion: a power-performance simulator for interconnection networks," in *MICRO 35: Proceedings of the 35th annual ACM/IEEE international symposium on Microarchitecture*. Los Alamitos, CA, USA: IEEE Computer Society Press, 2002, pp. 294–305.

[10] http://www.ocpip.org.

Project 5

Guaranteed Hybrid Simulations

Researcher: Shams Karamkhan[1]
Mentor: Alessandro Abate[2]

5.1 Overview

In nature, engineering and mathematics objects change (shape, position, composition) with time. In other words, they are time-dependent. Systems Engineering aims at describing these phenomena with proper mathematical models. The dependence on time can be either continuous (as in analog phenomena), or discrete (as in digital objects). The science of Hybrid Systems (HS) tries to build up mathematical models able to describe these phenomena systematically. Now, there's no free lunch here; HS are tough to analyze.

Specifically, one of the first subtleties is the "mathematical brittleness" of the trajectories of the systems (more rigorously, we say that the trajectories are not continuously dependent on initial conditions). If we simulate a trajectory with a tool like MATLAB, for instance, we introduce some uncertainty, or rather some errors. These errors can be very disruptive in some cases (which we call "pathological").

It turns out that we can control these errors (we can refine the simulation for instance). This is the idea that underlines the project: controlling the errors, i.e. refining the simulations, in order to make sure that the simulated trajectory does not encounter these pathological cases and is instead "safe"; moreover, this also means that the actual trajectory will have the same "shape" (behavior, evolution) of the simulated one.

This idea will be possibly embedded in the currently available simulation tools for HS. It should be added to the Hyper framework.

5.2 Technical Tasks

Develop necessary skills for Programming (C(++), MATLAB), understanding the rudiments of numerical analysis, and willingness to learn them.

5.3 Preparatory Tasks

Before arriving, the following tasks should be done by the student:

1. Refresh your knowledge of MATLAB (necessary);

[1] Shams Karamkhan is a rising senior at Wright State University, majoring in Electrical Engineering.

[2] Alessandro Abate is a PhD student at the University of California, Berkeley, in the Department of Electrical Engineering and Computer Sciences, working with Prof. S. Shankar Sastry.

2. Be prepaerd to be doing simulations in C, or C++; if the student has no knowledge, he should think about learning some basic stuff (e-mail me with questions);

3. Read some simple primer about differential equations and numerical analysis.

Regarding task 3, any simple primer would work.

Bibliography

Project 6

A Hybrid Systems Model of Double Support Phase of a Bipedal Walker

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Mentor: Aaron D. Ames[2]

Bipedal walkers (humans included) are fascinating, and amazingly complex, systems. Despite the recent publicity of walking robots such as Sony's Qrio and Honda's Asimo, many of these robust robots do not exhibit a human-like gait, due to design decisions made to simplify the controller—the result is fundamentally *static* rather than *dynamic* walking. This project will seek to apply new and emerging techniques in the analysis and design of hybrid systems to incorporate the *double support phase* in the model of the system.

6.1 Overview

"Passive" bipedal walkers (that is, robotic walkers that do not require actuation) can walk down shallow slopes with gravity as their actuator. Several researchers have demonstrated the theory and application of these walkers (see [1, 2, 3, 4]). Although, there is still a vast amount of analysis that needs to be done on these walkers as most of the techniques employed to date are empirical rather than analytic.

Bipedal walking is all about finding stable limit cycles in the dynamics. The thesis in [5] explains the whole modeling and simulation process. Currently all walkers (passive and actuated) only have one foot on the ground at the same time, i.e., they only have a single support phase. We would like to extend this analysis to a double support phase (by adding feet). The way to do this is to find limit cycles for the systems, including analysis and modeling/simulations, and will be in direct interaction with Project 1. Where to go from there depends on interest of the student.

6.2 Technical Tasks

Possible tasks include,

- controlling passive walkers to achieve walking on flat slopes (for an example of the mathematics that it takes to start talking about controlling bipedal walkers, look at the paper by Grizzle [6]. Note how basic the math is in the passive walker's papers [5] when compared to the math in [6].

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- use of new techniques for analysis.

Note that the mathematical approach we will use to attempt this problem will be different than that used in the bibliography papers. We will have to use hybrid systems because of the introduction of the double support phase. With regard to hybrid systems, we will go through what you need to know.

6.3 Preparatory Tasks

Before arriving, the following tasks should be done by the student:

1. There are some web pages to look at:
   (a) http://ruina.tam.cornell.edu/research/topics/locomotion_and_robotics/overview.htm
   (b) http://www-personal.engin.umich.edu/~artkuo/Passive_Walk/passive_walking.html
2. Some Matlab code for simulating a passive walker is available here: If you could get this code working before we start is would be interesting (although this is not required). http://tam.cornell.edu/students/garcia/msghomepage.html
3. Here is the page of the best bipedal passive walker built to date. The problem is that he did it ad hoc, no real analysis was done. http://www-personal.engin.umich.edu/~shc/robots.html
4. See what other papers and application you can find on your own (look in the references of the papers that I sent you). While reading these papers, you should keep in mind the goal of the project.

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