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A Summer Program to promote an Integrated Undergraduate Research and Group Design Experience

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A Summer Program to Promote an Integrated Undergraduate Research and Group Design Experience

Introduction

The NSF REU program provides undergraduate students in engineering and related fields an opportunity to participate in ongoing active research programs, including the development of micro air vehicles, multi-modal robots, active flow control, aeroacoustics, sensors and actuators, smart materials, etc. The multidisciplinary nature of these projects has engaged students in cross-cutting technologies by inspiring the integration and synthesis of ideas and facilitating a better understanding of engineering design at the system level.

For the past two summers, we have recruited 33 REU students, 22 external and 11 internal students into the program. Among external participants, seven are international exchange students from three Brazilian universities. During the 10-week summer program, they were assigned to 31 projects supervised by 10 engineering faculty and 18 postdoc/graduate student mentors. In addition to their individual projects, REU students were engaged in group activities including a group design project, research lab tours, weekly seminars, outreach and social activities. The summer programs were culminated in a whole-day research symposium with individual and group presentations plus poster sessions.

One unique aspect of the program is the integration of the group design experience into the summer program. Students were assigned in groups to work in design projects relevant to their assigned research tasks. Group collaboration sessions were reserved for all REU students to share their experiences and work on group projects. Two open-ended design projects were implemented: (1) Use of smart materials to develop multi-modal movement and agility in 2012, and (2) The development of a quad-rotor aircraft with indoor maneuverability in 2013. In the paper, we will discuss lessons learned in the coordination of the group project and propose a strategy to optimize the integration of REU students' individual research efforts with the group design project to further enhance the overall REU experience.

Program Overview

Over the past two summers (2012-13), through dedicated REU web site, direct solicitation via Department Chairs, personal communications, and internal recruitment events, we received more than 100 applications and successfully recruited a total of 33 Fellows to the program. Out of the 22 external Fellows, 7 are Brazilian students who had studied at our College in international exchange programs and were invited to participate in the summer program although without NSF financial sponsorship. The involvement of internal students from the College proved to be valuable since they can readily engage external Fellows to familiarize them with the academic surroundings as well as the local living accommodations. We recruited an internal 2012 REU alumnus to serve as a program assistant in 2013 for much better coordination of program logistics and activities.

To maximize their learning experiences, we designed two types of activities: (1) Individualized projects to be supervised directly by their respective faculty advisors and designated mentors. (2) Collaborative group activities including seminar series, field trips, social events and the group design project. In particular, the group project is designed to provide a platform for all students to function in teams while cogitating from an integrated system perspective. Engineers at heart are designers. They have made tremendous contributions to society in developing products to enhance the quality of life. Even while pursuing advanced research activities, engineers always seek avenues to build new devices while improving existing ones. The project-based learning (PBL) methodology stipulates the integrated process of concept generation, need assessment, engineering selection and project realization and can cultivate high level skills such as better decision making, critical thinking and leadership.[1] This is a critical element of our program and will be further discussed in a later section. A typical timetable for these activities is included in Table 1 as a reference.

Table 1. 2012 REU Summer Program Weekly Activity Schedule

<table>
<tr><th></th><th>Monday</th><th>Tuesday</th><th>Wednesday</th><th>Thursday</th><th>Friday</th></tr>
<tr><td>8:30-12:00</td><td colspan="4">(A) Individual Research
* REU-MASS orientation Monday the first week</td><td>** REU research symposium on Friday, the last week</td></tr>
<tr><td>12:00-1:00</td><td colspan="5">Lunch Break</td></tr>
<tr><td rowspan="2">1:00-5:30</td><td colspan="2" rowspan="2">Individual Research</td><td rowspan="2">(B) Group Design project/ competition preparation</td><td>(C) Group Collaboration Session</td><td rowspan="2">(E) Industry and Lab Visits, Outreach, or Social Interaction</td></tr>
<tr><td>(D) Weekly Seminar</td></tr>
</table>

Individualized Research Projects

Each REU fellow will directly participate in regular research activities together with faculty and other research personnel in one or more of our research laboratories. They may assist a research assistant in setting up an experiment or perform data analysis under the supervision of the faculty researcher. This layer of interaction will allow them to become familiar with the specific research topics and the daily routines performed by engineering researchers. They will learn specific skills in terms of software and experimental data acquisition and analysis, as well as the basic theories needed to understand fundamental concepts applied to engineered technologies. This will prepare them to define the relevance between the advanced research subjects and the general engineering products that they come across on a daily basis.

In summer 2012, as shown in Table 2, a total of 18 REU Fellows were assigned into 16 projects; 15 individual projects and 1 group project for three Brazilian exchange students since they had to return to Brazil early to start the next school year. Another 15 projects were assigned to 15 REU Fellows in summer 2013 (Table 3). Among those REU Fellows, 4 are African American, 6 are women, 2 are Hispanic American and 7 are international exchange students. In addition to the ten REU faculty, we have recruited 18 graduate students and postdocs to serve as project mentors through these two summers. The titles, faculty and delegate mentors for all REU individual projects are also listed in Tables 2 and 3, respectively. These project topics range from unsteady aerodynamics, flow control, robotics, autonomous control algorithms, field-coupled solid mechanics of smart materials, development of sensors and actuators, etc. Most of these projects are currently funded by federal or state governments and private industry and they represent a wide cross-section of engineering research subjects.

Table 2. List of Summer 2012 Projects, Mentors and REU Fellows

No.		Faculty	Delegate Mentors	Titles
1	Colby Borchetta	Sam Taira	Phillip Munday	Development of Wind Gust Rejection Techniques for MAVs
2	Bereket Abraham[1]	Chiang Shih Sam Taira	Phillip Munday	Active Flow Control for Bluff Body Wake Flows
3	Paul Miles	William Oates	Mike Hays	Characterization of field-coupled materials behavior of active materials.
4	Lucas Aguiar[4]	Emmanuel Collins	Camilo Ordonez	Terrain Classification for Mobile Robot
5	Warren Jones[1]	Emmanuel Collins	Oscar Chuy	Graphical User Interface for Implementation of SBMPO Algorithm
6	Kyle Miller[1]	Emmanuel Collins	Oscar Chuy Camilo Ordonez	Using Open Dynamics Engine for the Simulation of Robotic Systems
7	Alex York	Jonathan Clark	James Dickson	Reduced-Order Experiential Model for Running with Curved Legs
8	Asa Darnell	Jonathan Clark	Jason Newton Bruce Miller	MTS C-leg Testing Apparatus SCARAB Dynamic Running Development
9	David D'Alessandro	Farrukh Alvi Rajan Kumar	Phil Kreth	Microjet Visualization and Characterization
10	Naomi Llinas[2,3]	Farrukh Alvi Rajan Kumar	Ted Worden	Impinging Jet Studies
11	Clay Norrbin	Jonathan Clark	James Dickson Bruce Miller	Design and Fabrication of Testing Platforms
12	Piero Caballero[3]	Juan Ordonez	Alejandro Rivera	Biologically inspired extended surfaces for heat transfer enhancement
13	Sarah Waddill[2]	Jonathan Clark	James Dickson	Adapting a Dynamic Climbing Robot to Tree Climbing
14	Yasmin Belhaj[2]	Farrukh Alvi	Phil Kreth	Visualization and Characterization of Micro-Actuators using Schlieren
15	Teresa Wright[2]	Farrukh Alvi	Erik Fernandez	Using Particle Image Velocimetry (PIV) to Characterize Separation Control Effectiveness
16	Gustavo Krupa[4] Eduardo Krupa[4] Vitor Ribeiro[4]	Chiang Shih	Keith Larson	Development of autonomous aerial vehicles

Table 3. List of Summer 2013 Projects, Mentors and REU Fellows

No.		Faculty	Delegate Mentors	Titles
1	Daniel Canuto	Sam Taira	Philip Munday	Characterization of airfoil performance for Martian air vehicles
2	Luiz Paes[4]	William Oates	Justin Collins	Electroactive origami-based elastomers for advanced robotic and aerodynamic structures
3	Chris Rodenborg	William Oates	Matt Worden	Connecting quantum and continuum length scales in multifunctional materials
4	Barry Pawlowski	Wei Guo	Jian Gao	Laser ionization in helium for visualization of quantum turbulence
5	Jason Brown	Emmanuel Collins	Oscar Chuy	Modeling and Control for Micro Aerial Vehicle (Quadrotor)
6	Dung Tran	Emmanuel Collins	Camilo Ordonez	Modeling and Control of Stunt Jumping RC car.
7	Sondra Miller[1,2]	Emmanuel Collins	Oscar Chuy	Kinematic Model Verification of Skid Steer Vehicle
8	Darren Tinker	Emmanuel Collins	Camilo Ordonez	Development of Self Contained Laser Mapping Tilt Platform
9	Kwoon Moon	Jonathan Clark	Jason Newton	Hierarchically Compliant Claws for Improved Climbing and Perching
10	Diego Soler[4]	Jonathan Clark	Bruce Miller	Adaptive Robotic Feet Design for Variable Surfaces/Inclines
11	Traci Chang[2]	Jonathan Clark William Oates	Jason Newton	Design of Smart Material Fingers and Legs for Improved Grasping and Running
12	Russ Hamerski	Lou Cattafesta	Adam Edstrand	Experimental characterization of pressures sensitive paint within an acoustic impedance tube
13	Ernandes Nascimento[4]	Juan Ordonez	Alejandro Rivera	Biologically inspired extended surfaces for heat transfer enhancement
14	Ben Patterson	Rajan Kumar	Brian Davis	Thrust and impact load measurements of supersonic impinging jet at high temperatures
15	Harrison McLarty	Rajan Kumar	Chase Foster	Design, fabrication and testing of a six-component strain gage balance calibration

Note for Table 2 and 3: [1] African American, [2] Women, [3] Hispanic American, [4] International Students

Group Design Project

A group design project was included as part of the REU program to expose students to open ended projects within a team environment. The goals of the project included overarching emphasis on applications in product design and management applied to robotics, aerospace, and integration of adaptive structures. We summarize here evolution of this project over the first two years of the REU. Plans for year three are briefly discussed with additional details about future plans in subsequent sections.

In year 1, a design goal was proposed to construct an adaptive structure capable of enhancing locomotion of an existing robotic platform. This topic was chosen due to its relatively pervasive application of materials and adaptive structures in robotics and aerospace structures. The particular material under consideration was the dielectric elastomer, VHB 4910, made by 3M. These materials are relatively inexpensive and can be actuated with high voltage/low current amplifiers that are lightweight (EMCO amplifiers, $200-$300, 20-100 g). Presentations by faculty involved with the REU students were provided as motivation illustrating how these materials have been used in controlling the lift and drag of micro air vehicles and changing the dynamic response of legged robots. The aim was to have the students engage their respective faculty and graduate student mentors to understand the problem and seek mentoring advice about potential designs.

Not only was the design open ended, but we also recommended that the group select their own team(s) and sub-groups. We recommended that the REU students work either as a single team or break into multiple teams. This offered the option of developing different designs within a single group or competition among two groups. Upon deliberation and presentations of the project, the group decided to divide into two teams. A set of milestones and mentoring plan was established during the first week in close collaboration with the responsible faculty, Oates and Shih. These milestones included development of the engineering structural design, system dynamic identification, modeling, testing, and control. We left group organization relatively open, but suggested four functional groups: 1) adaptive structure design and modeling, 2) hardware testing and control design, 3) manufacturing and testing, and 4) bio-inspired robotic articulation. Distinctions between 1) and 4) were discussed to delineate differences in bio-inspired concept generation versus analytical model testing and verification prior to experimental validation. Laboratory space, materials, experimental equipment, and robotic platforms were also provided for development and integration with faculty research laboratories to foster mentoring over the course of the summer. We also introduced the REU students to graduate students working in other laboratories within our research building to facilitate mentoring on a daily or weekly basis.

As the two teams developed their design concepts, the approaches were very different. One group developed an aerodynamic wing structure while the other group focused on an actuator for legged robots. Thus, the teams did not directly compete, but collaborated in an unexpected yet interconnecting manner. It is believed that this may have been motivated by prior research of several faculty involved in the REU program. Prior research within the group at the College has focused on development of a robotic platform that could climb a wall, disengage, and fly. Both teams explored methods to use VHB membranes to achieve enhanced mobility centered on this multi-modal locomotion concept.

The students quickly realized the challenges encountered in this type of open-ended design project. In itself, adaptive material integration is not trivial to implement and operate reliably. Furthermore, complexities involved in modifying the robotic platform impeded transitioning the design to a working prototype. Many interesting concepts were proposed on paper, only to find out that these concepts failed in the laboratory setting. One of the lessons learned by the end of the summer was the need to conduct more thorough analytical models and preliminary assessments prior to fabrication and experimental implementation. This was found to be one of the common mistakes during the implementation of the first year group design program. From the overall supervisory perspective, Oates and Shih also realized that a completely open-ended project might not be suitable for a relatively short (10 week) program. In particular, the group project is only one component of assigned learning activities for all REU students. Clearly, we do not want to jeopardize the core objective which is to enhance their individual research experiences. Based on feedback, we decided to modify the operational format during the second year. Notwithstanding, we consider the overall concept a success since the majority of the students were engaged in the design project and gained experience working in a team and working on a very challenging design project. Furthermore, they gained excellent appreciation for the time and effort necessary to design an engineering system from scratch.

In year 2, we altered the design project based on lessons learned as discussed. We decided to provide more structure to the organization of the group project. Primarily, we provided an un-assembled quadrotor as a test platform for the group to build, test, and deploy using GPS with the goal of achieving a set of mobility tasks and active interaction with designated targets. This provided a clear goal for the group: assemble the quadrotor and have it operational for a controlled drone application. If successful, a competition involving locating and engaging targets was to be conducted near the end of the summer. The REU group worked together quickly in one team with clear organization and assigned responsibilities. They successfully assembled and started testing the quadrotor within a few weeks. Unfortunately, they fell short of getting the system fully operational for navigating and locating a target.

Faculty worked with the group on a weekly basis to identify challenges and potential design solutions. It was the student's responsibility to identify parts needed and resources necessary to make the quadrotor functional. The group divided into two sub-groups where one group focused on assembly and testing of the quadrotor while the second sub-group focused on developing a device that can engage a target. The device chosen for engaging a target was an airsoft gun due to its light-weight properties, ease of modification for quadrotor mounting, and electric control for firing ammunition. This sub-group successfully modified the airsoft gun and designed a mounting system that consisted of a two degree of freedom gimbal for aiming at a target. A laser pointer was to be used for visual confirmation of the target. The other sub-group that was involved with assembly and testing of the quadrotor successfully assembled the drone and began troubleshooting the hardware/software interfaces for motor control. The students spent significant time working with motor control and learning about proportional-integral-derivative (PID) control designs.

Motor control of the quadrotor presented significant challenges for the group. It is believed that this is due to the lack of knowledge of control theory for junior and sophomore mechanical engineering students. Faculty provided mentoring and encouraged collaborations with graduate students and postdocs in controls who are currently conducting research on path planning of quadrotor drones. This was anticipated to help the REU group to overcome lack of knowledge of control theory. Ultimately, the group fell short of getting the quadrotor fully operational in hover mode and navigation. Despite this limitation in achieving the goal of the design, the students made great progress in building and testing the quadrotor. The faculty also learned a great deal in understanding the challenges in the development of this system which will guide key changes in in year 3. This is discussed in the section on Future Plans.

Other Professional development and Group activities

In addition to the group design project, we have arranged various activities to enhance their learning experience through professional development sessions and activities to promote group interaction and community outreach. They include:

(A) Group collaboration session: Every Thursday afternoon, a two-hour group discussion session will be reserved for all REU students to share their experiences during the week. They may exchange concepts on design competition, seek moral support from each other, or reach collective opinions to feedback to program director on program improvement. This interaction will bring them closer together to nurture long-term partnerships and maximize their achievement through experience sharing. REU students are empowered for the organization of this session with minimal supervision.

(B) Weekly seminar and professional development session: The first few sessions will deal with teaching the students good research practices, including design of experiments, laboratory safety, data and error analysis. Other seminars will be dedicated to professional development issues such as professional ethics & responsible conduct of research, how to be successful in graduate school, career path decision, and effective technical communication. Finally, selected research topics will be given by both participating faculty and other invited speakers to broaden the background of the REU students beyond their own subjects. A list of presenters and seminar topics is included in the Table below.

Table 4. REU Weekly Seminar Series

Presenters	**Topics**
Chiang Shih/Janice Dodge	Program orientation/Lab Safety
Chiang Shih	Responsible Conduct of Research (RCR)
Jonathan Clark	Robotics
Rajan Kumar	Supersonic Flow Research
Eric Hellstrom	Technical Communication
Emmanuel Collins	Graduate School and Career Options
William Oates	Active Materials
Sam Taira	Computational Fluid Dynamics
Emmanuel Collins	Autonomous Motion Control
Farrukh Alvi	Active Flow Control
Chiang Shih	REU Open House & Poster Session

(C) Other enrichment activities: these include lab visits to local research facilities including National High Magnetic Laboratory, Center for Advanced Power Systems and High Performance Materials Institutes. Other off-site visits include touring a local manufacturing company, Danfoss Turbocor, Inc., and a field trip to visit the nearby Air Force Research Laboratory at Eglin AFB as well as the Coastal Marine Laboratory. Other informal social events include Friday lunches, volleyball games, and a half-day excursion to the Tallahassee Challenger Learning Center along with outreach activities including egg drop, aircraft building and testing, and legged robotic demonstration.

International Component

Another unique feature of our program is the inclusion of international students. For several years, our College has hosted international exchange students from Brazil, Nigeria and China. In particular, Shih has developed a US-Brazil partnership program with one U.S. partner, University of Pittsburgh, and two Brazilian universities: Federal Universidade de Itajuba (UNIFEI) and Federal Universidade do Parana (UFPR). For the past three years, several

Brazilian students participated in the program undertaking year-long studies at our program. For the past two summers, six of them were invited to participate in the summer program before heading back to Brazil. In addition, another student from the Brazil's Science Without Borders also participated to fulfill his internship requirement. These students had been assigned with their individualized projects and actively involved in group design activities. All exchange students have had U.S. academic experience before the summer program and integrate smoothly with the program.

Due to limited resources, we have not devoted too much effort to expand the international component but feel that all participants have benefitted by broadening their cultural and scientific communication skills interacting more closely with their international counterparts. Future inclusion of exchange students from Nigeria and China is being considered for the coming 2014 program. The international component is not formally sanctioned by NSF and these students are supported by Brazilian government without financial assistance from the REU program.

Future Plans

In general, we are happy with the progress of our program. Most activities are well organized while providing desired learning experiences to students. As a result, we will focus only on the group design project for further optimization. By recognizing its importance to the program and operational shortcomings we learned from the previous two years, key modifications will be implemented in 2014. Instead of managing individual and group projects as two separate activities, we would like to devise a plan to integrate them more closely. From lessons learned during the previous two summers, we suggest the enactment of the following three corrective steps: (1) Provide more organizational structure to guide students to function more efficiently in the design project; (2) Prepare students with skills needed for expedite project implementation; (3) Involve REU faculty early in the process to develop technical connection between individualized research projects and the group design project. The last point is critical so students have holistic learning experience while transitioning between two activities.

We decided that the quadrotor platform will remain the central development platform for year three. The design of the autonomous platform imposes an interdisciplinary approach to integrate aerodynamics, path planning, autonomous control, mechatronics, all topics covered in our research themes. Active materials, robotics, image visualization and flow diagnostics can also easily be required for multi-tasking design missions. Accordingly, we will ask faculty and postdocs to give tutorials early during the program on key concepts to overcome limitations in student knowledge that is critical to achieve the design goal. Last summer we asked the students to identify laboratory equipment and quadrotor parts that might be needed. This actually encouraged timely planning and thinking to identify potential problem areas before it was too late. Similarly, we will request the students to self-assess their skills and knowledge which they consider lacking in order to plan supplementary tutorial sessions on an as-needed basis. Additional methods to identify epistemic uncertainty are discussed in the following section. We expect this active learning tactic can enhance their cognitive skills in identifying things that they know that they do not know.

Furthermore, we recognize the need to foster closer collaborations among REU faculty supervising individual research projects. A planning session will be dedicated to the integration of individual research topics and group design project before the start of the summer session. Knowing the difficulty for full integration, we will not require that each individual research project to be strictly coupled with the quadrotor platform, but we will make all efforts to engage faculty so certain interrelated themes could be identified. As a matter of fact, such discussion could likely lead to unique multidisciplinary applications linking various groups conducting research in aerodynamics, materials, flow control, and robotics.

Uncertainty Quantification of Accelerated Learning

One of the challenges in gauging student learning is the development of proper methods of assessment that ultimately lead to objective feedback about accelerated learning. As engineers, we often modify our education programs with good intentions; however, rigorous methods of effective assessment are often lacking or misguided. As part of our future REU programs, we plan to use uncertainty quantification and graph theory to understand how students learn in complex environments such as a group design project. This is motivated by recent initiatives developed by the Oates which entails implementation of the Dempster-Shafer theory of evidence.

Uncertainty quantification can be broadly characterized by probability theory, interval analysis, and the Dempster-Shafer (DS) theory of evidence. The latter is ideal in situations where some knowledge of the data or expected outcome is known, but not fully understood. It is also ideal in situations with limited data unlike probability theory (e.g., Bayesian statistics). It is therefore ideal for the third year of our REU program since some information is known, but we have limited data from a total of 33 students. Each summer, surveys are given to the students and faculty about their experience. Within the DS theory, data or opinions from different 'experts' (e.g., students, graduate students, and faculty) will be analyzed by constructing m-functions as well as plausibility and belief functions that form probability mass functions to quantify statistical information about student and faculty responses of their experiences as discussed by Liu and Yager[2]. Unique to the DS theory, is the ability to combine data using Dempster's rule or more advanced rules such as Yager or Inagaki's rules. Through these rules, we can combine probability mass functions to gain more insight on the probability of some measure of success according to the surveys. This will provide a measure of agreement or possible disagreement among the students and faculty. Such measurements will provide a tool of consensus to further enhance certain aspects of the program. In areas of quantifiable disagreement, faculty involved with the REU will discuss issues to determine a method to move forward. Ultimately, this mathematical algorithm will provide a tool for faculty to make decisions about the future of the REU program in the presence of uncertainty and limited survey data.

The second concept is based on graph theory and is motivated by recent discussions at a National Academy of Engineering, 2013 Frontiers in Engineering Education meeting attended by Oates. The concept, known as Epistemic Network Analysis, has been implemented at the University of Wisconsin[3] in which a capstone design project included documentations of student interactions through Wiki discussion boards. Tracking student discussions was plotted using graph theory. This theory provides a rich set of probability measures to understand learning[4]. In other applications, it has been coupled with Hodge theory for ranking problems such as the Netflix prize where algorithms are desired to more accurately predict movies a person may enjoy based on a very limited database of 1-5 star rankings. With respect to pedagogical research and development, quantification of edge weights between nodes within a social network graph (e.g., amount of discussion among REU students) can be quantified in terms of the potential or divergence at a node (e.g., an REU student) and compared with rotational operations of regions of the graph[5]. This leads to ranking methods to help understand which students are engaged in discussions of certain topics. For example, a discussion thread on close-loop control may include many posts among a specific set of students (e.g., higher edge value among nodes and hence higher potential or divergence). Rotation measures among triads may also be useful to understand disagreements where faculty can step in to facilitate design decisions. Generally speaking, faculty can quickly review the graphs and identify students who need mentoring on a specific topic. In other words, it is anticipated that this assessment tool will provide a way to create just-in-time teaching which is critical for a 10 week summer project. Furthermore, it is pervasive in any course and therefore a worthy exercise to conduct on an open ended design project to assess its effectiveness in improving REU students design project experience.

Summary

An overview is provided about our experience in conducting two summer REU programs in 2012 and 2013. The program provides individualized research experiences in multidisciplinary topics such as micro air vehicles, multi-modal robots, active flow control, aeroacoustics, sensors and actuators, and smart materials by leveraging diverse expertise of a group of engineering faculty engaged in research. In addition, REU students were also engaged in group activities including a group design project, research lab tours, weekly seminars, outreach and social activities.

One of the objectives of the program is the integration of the group design experience into the summer program. In doing so, students were assigned in groups to work in design projects relevant to their assigned research tasks. In this paper, we reported our overall experience in carrying out this concept by assessing our shortcomings in implementation while proposing corrective actions for the future improvements of the unique pedagogical approach.

Finally, we propose the use of uncertainty quantification and graph theory methodologies to assess students' learning in order to further improve our implementation of the integrated individualized research and group design experience.

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