Electrical and Computer Engineering: Curricula without Boundaries

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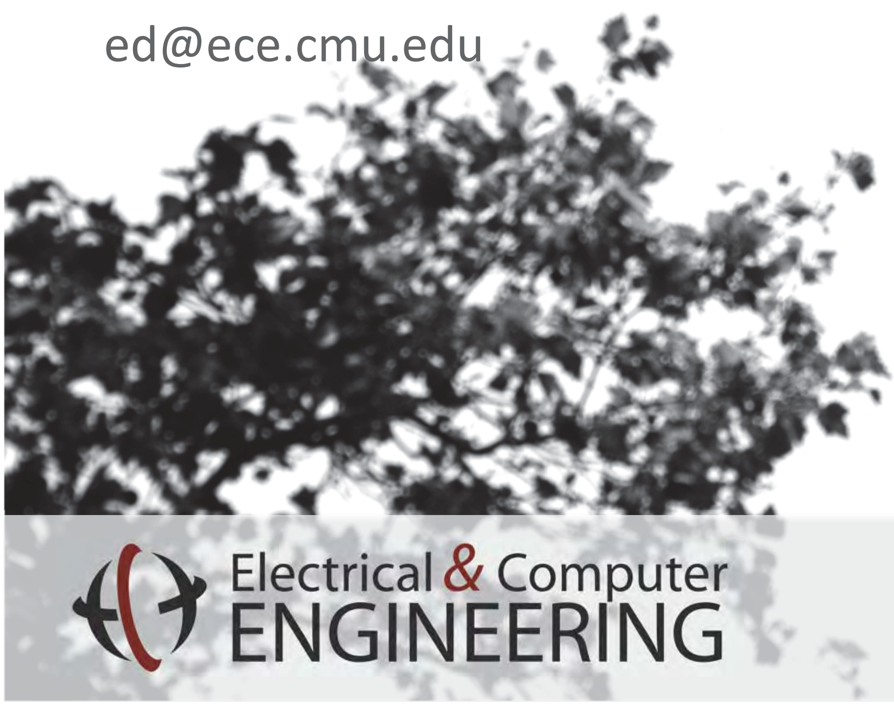
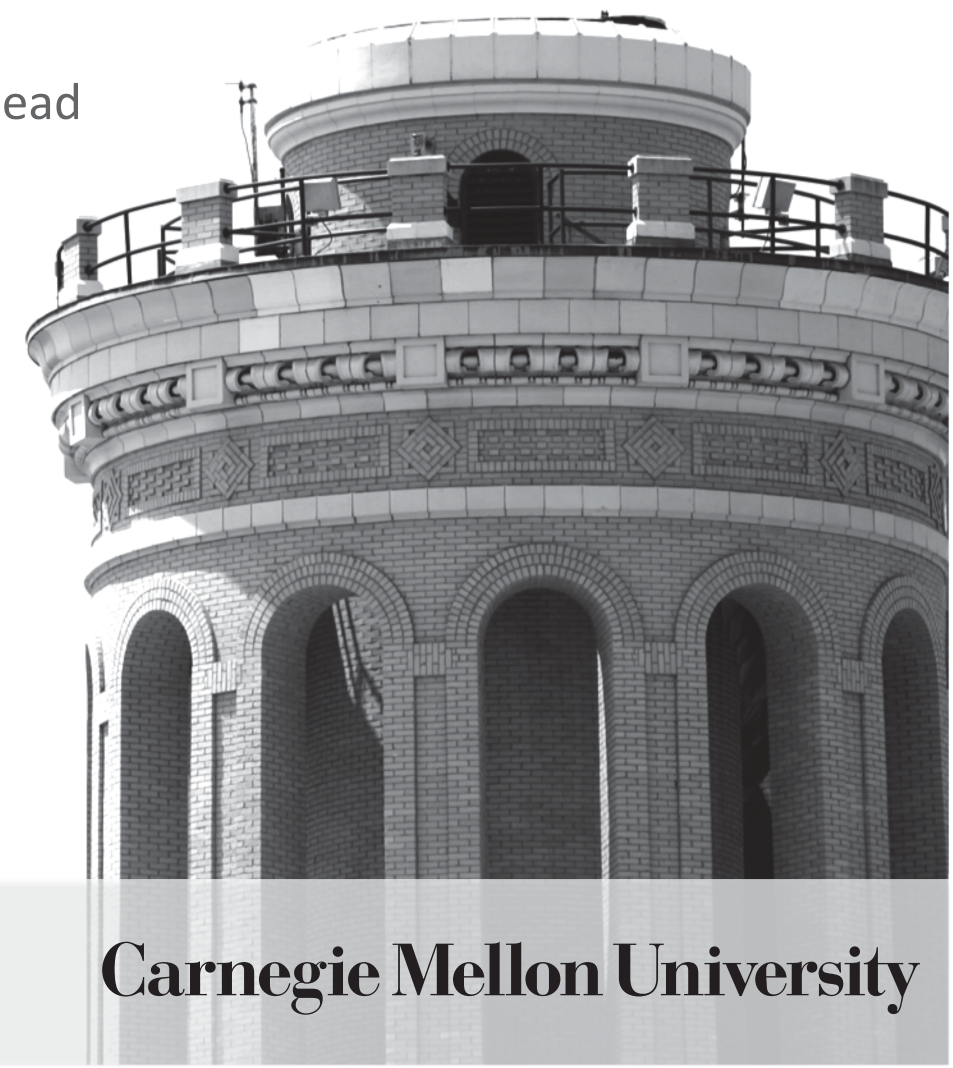




Carnegie Mellon




10,402 undergraduate and graduate students

1,426 faculty members

8:1 student to faculty ratio

72,496 alumni

50 U.S. alumni chapters

20 international alumni chapters

10 degree programs in 12 countries

Carnegie Mellon

Research

- $360+ million per year in sponsored research

Award Highlights

- 18 Nobel Prize Laureates
- 11 Turing Award Winners
- 42 National Academy of Engineering Members
- 12 National Academy of Sciences Members
- 18 American Academy of Arts & Sciences Members
- 36 Fulbright Scholars
- 96 Emmy Award Winners
- 24 Tony Award Winners
- 6 Academy Award Winners

CIT (College of Engineering)

- Biomedical Engineering
- Chemical Engineering
- Civil and Environmental Engineering
- Electrical and Computer Engineering
- Engineering and Public Policy
- Materials Science Engineering
- Mechanical Engineering

ECE by the numbers:

- ECE includes over 1000 individuals
- Faculty Members
  - 50 tenure-track
  - 10 research/teaching
  - 38 courtesy
  - 13 adjunct/special
- 80+ Staff members (technical and non-technical)
- 460+ undergraduate students (not incl. Freshmen)
- 500+ graduate students (M.S. and Ph. D.)
- More than $32 M/year total research expenditures

Many Research Labs and Centers

ECE Programs – Physically Distributed

Pittsburgh, PA.

BS, MS & PhD degrees in ECE

Contact: Ed Schlesinger, ed@ece.cmu.edu

Silicon Valley, CA.

MS degrees in Software Engineering, Soft. Management, IT, ECE & PhD in ECE

Contact: Martin Griss, martin.griss@sv.cmu.edu

ICTI, Portugal

PhD degrees in ECE

Contact: Jose Moura, moura@ece.cmu.edu

Dehli, India.

BS degree in ECE

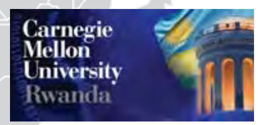
Contact: Ed Schlesinger, ed@ece.cmu.edu

Shiv Nadar University
Carnegie Mellon University

Kigali, Rwanda.

MS degree in Information Technology

Contact: Bruce Krogh, krogh@ece.cmu.edu



Guangzhou, China.

Dual-degrees for MS & PhD in ECE

Contact: Jimmy Zhu, jzhu@ece.cmu.edu

Joint Institute of Engineering
SUN YAT-SEN UNIVERSITY
Carnegie Mellon University

Singapore

PhD in ECE

Contact: Ed Schlesinger, ed@ece.cmu.edu

Agency for Science, Technology and Research
SINGAPORE

Entrepreneurship - ECE Spin Off Companies

- Ansoft (1984) Cendes
- Ultrasystems (1986) Siewiorek
- Dasys (1991) Thomas
- PDF Solutions (1991) Maly Strojwas
- Quantapoint Inc (1992) Khosla, Kanade
- Omniview (1992) Siewiorek
- Inmedius (1995) Siewiorek
- Scalable Networks (1996) Bianchini, Kim
- TimeSys (1996) Rajkumar
- Neolinear (1997) Rutenbar, Carley
- Xactix (1998) Gabriel
- Applied Electro Optics (1998) Schlesinger, Stancil
- Panasas (1999) Gibson
- Spinnaker Networks (1999) Bianchini
- Accelight Networks (1999) Kim
- Proxicast (2000) Peha
- Akustica (2001) Gabriel
- IC Mechanics (2001) Carley
- Verimetra (2001) Gabriel
- Cyphermint (2002) Peha
- Helium Networks (2002) Hills
- New Electricity Transmission Software Solutions (2002) Ilic
- Extreme DA (2003) Pileggi
- Fabbrix Inc (2004) Pileggi, Strojwas
- Cardiorobotics (2005) Choset
- Medrobotics (2005) Choset, Wolf, Zenati
- Xigmix Inc. (2005) Li, Pileggi
- Testworks (2007) Blanton
- Silicon Vox (2007) Rutenbar
- Wombat Security Technologies (2008) Cranor
- Butterfly Haptics (2008) Hollis
- X5 Systems (2008) Lohn
- SpiralGen (2009) Franchetti, Hoe, Pueschel, Voronenko, Moura
- YinzCam (2009) Narasimhan, Ghandi
- Virtual Traffic Lights (2009) Tonguz
- Apportable (2010) Jackson
- Transactional DA (2010) Hoe
- NoFuss Security (2011) Gligor, Perrig, Khosla
- ZetL Technology (2011) Zhu, Laughlin

The landscape

- The characteristic of scientific and technological development in the 21st century will be the continued erosion and elimination of “disciplinary” boundaries both intellectual and geographical

- Of all the engineering and science “disciplines” ECE is most well suited to this environment.

- ECE has “reinvented”, “refocused”, “redefined” itself and can most easily thrive in such an environment.

… more well defined in the past…

THEORETICAL ELEMENTS

OF

ELECTRICAL ENGINEERING

BY

CHARLES PROTEUS STEINMETZ, A.M., Ph.D.

THIRD EDITION

THOROUGHLY REVISED AND GREATLY CORRECTED

NEW YORK
McGRAW-HILL BOOK COMPANY
239 WEST 39TH STREET
1909

CONTENTS.

PART I.

GENERAL SURVEY.

The Evolution of ECE

- The focus of Electrical and Computer Engineering as an academic field has evolved over the last hundred years.
  - Initially focused on electric machines and power, then radar and communications (radio, television), then electronics and computers
  - Today ECE as a field permeates nearly all aspects of society and the academic work done by practitioners of this field impacts peoples lives deeply and broadly

ECE Today I

- *adaptive algorithm infrastructure*
- *adaptive computing systems*
- *agent-based computational economics*
- *agricultural meteorology*
- *algorithms in computational electromagnetics*
- *amorphous silicon and nanocrystalline materials for renewable energy*
- *analog and mixed-signal VLSI*
- *analog to digital (ADC) and digital to analog (DAC) converters*
- *antenna analysis and design*
- *applied algorithms*
- *applied electromagnetism*
- *applied software engineering*
- *architectural support for security*
- *architectures and compiler techniques for software protection*
- *atomistic modeling of microelectronic processes*
- *automation tools for improving productivity and reliability of software*
- *bandwidth recycling*
- *Bayesian approaches*
- *big data and cloud computing*
- *bioinformatics*
- *calculation of properties of bulk materials and surfaces*
- *chemical sensors from nano-memebranes and micro-cantilevers*
- *chemical-mechanical planarization*
- *code division multiple access (CDMA)*
- *collaborative networks for applications in product development and complex system operation*
- *combinatorial scientific computing*
- *compilers*
- *computational electromagnetics*
- *computer and network forensics*
- *computer architecture*
- *computer graphics*
- *computer networks*
- *computer vision*
- *computer-aided design of VLSI circuits*
- *conductivity of polymers loaded with conducting particles*
- *control of discrete event systems*

ECE Today II

- *control of nonlinear dynamical systems*
- *control theory*
- *cooperative communications*
- *counter-example analysis*
- *cross-layer design*
- *cross-layer jamming*
- *cryptography*
- *cyber security*
- *cyber-physical security of smart grid*
- *cyberphysical systems*
- *data mining*
- *data storage systems*
- *data visualization*
- *data-intensive scientific computing*
- *dependable computing*
- *design and analysis of algorithms*
- *design and layout strategies for performance optimization and yield enhancement*
- *design and simulation of photonic band gap crystals*
- *design of infrared sources and emitters*
- *design of magnets for magnetic resonance imaging diagnosis/prognosis*
- *digital signal processing*
- *directional antennas and receivers*
- *discrete and continuous optimization*
- *distributed and cloud computing*
- *distributed compression*
- *distributed systems*
- *domain decomposition methods*
- *dynamic memory management*
- *dynamical systems*
- *dynamics of rarefied gases*
- *economic theory*
- *electric machinery*
- *electric power markets*
- *electromagnetic aspects of high speed electronics and networking*
- *electromagnetic energy conversion*
- *electromagnetic methods of NDE*
- *electromagnetic simulations and wave propagation*
- *electromagnetic wave propagation and scattering*
- *electronic materials*
- *embedded systems*

ECE Today III

- *embedded systems software*
- *energy-aware computing*
- *error control coding*
- *evaluation of high performance computing systems*
- *fabrication and application of memristors in circuit design*
- *fault tolerant systems*
- *fault-tolerance*
- *finite-difference-time-domain simulations*
- *formal methods in intrusion detection*
- *genome assembly*
- *geometric modeling*
- *hardware/software co-design*
- *high- throughput DNA sequencing*
- *high-performance computing*
- *high-sensitivity miniaturized on-chip plasmonic MEMS sensors*
- *human computer interaction technologies*
- *hybrid organic/inorganic electronics*
- *image and video processing*
- *information assurance*
- *information retrieval*
- *inspection methods for the detection of cracks and corrosion in aircraft and nuclear power plants*
- *integrated filter design*
- *interconnection networks*
- *inverse scattering and nondestructive evaluation*
- *joint denial of service*
- *large scale and parallel computation*
- *light-induced defects and hydrogen motion in solar cell materials and devices*
- *local area networks*
- *low-density parity-check code design & analysis*
- *macroeconomics*
- *magneto optics and optical switching*
- *market coordination and learning*
- *materials informatics*
- *medical imaging*
- *metastability*
- *microelectronics/ semiconductors*
- *microprocessor off-load hardware for application acceleration*
- *microwave remote sensing*

ECE Today IV

- *MIMO Systems*
- *mining software repositories*
- *mobile computing*
- *model checking*
- *modeling matter and processes*
- *modeling of VLSI interconnects*
- *molecular dynamics simulations at the nanoscale.*
- *multi-user detection*
- *nanoscale phenomena*
- *nanostructured materials and ceramics for nano-photonics applications*
- *network analysis*
- *network coding – theory and applications*
- *network identity*
- *network inference methods*
- *network information theory*
- *network integrity modeling intrusion detection*
- *network testbeds*
- *network/channel coding*
- *networking*
- *neutron diffraction*
- *novel electromagnetic applications in microwave, millimeter-wave, infrared and optical wavelengths*
- *nuclear magnetic resonance in solids*
- *object-oriented systems*
- *op amp design*
- *open system verification*
- *optical communication and networking*
- *optical networks*
- *optical studies of solid*
- *optimized FPGA architectures*
- *optoelectronic materials and devices*
- *P2P networks*
- *parallel algorithms*
- *parallel and distributed computing*
- *parallel computer system design*
- *parallel methods in computational biology*
- *parallel numerical algorithms*
- *parallel tools*
- *parallel-computing methodologies*
- *pattern recognition*
- *pedigree assurance*
- *performance analysis of wireless sensor networks*
- *performance and scalability analysis*
- *performance evaluation*
- *pervasive computing applications*

ECE Today V

- *photonic band gap structures*
- *photonic crystals*
- *photonics*
- *physical layer based security and finger printing issues*
- *physical layer secrecy*
- *physical layers of optical and wireless networks*
- *power electronics*
- *power systems*
- *power systems analysis*
- *precision farming*
- *privacy-enhancing technologies for the Internet*
- *processing massive data sets and data streams*
- *program analysis*
- *program verification*
- *properties of electrically conducting composite materials*
- *QoS/overlay networks*
- *radio-frequency analog and mixed-signal integrated circuit design*
- *real-time systems*
- *reconfigurable circuits and systems for cognitive radio applications*
- *reconfigurable computing*
- *reconfigurable hardware*
- *regrowth of amorphized layers*
- *robotics*
- *scattering matrix formulations*
- *scientific computing in parallel fast multipole method*
- *secure real-time computing and communication*
- *security education*
- *security of distributed/ networked event-driven, real-time and hybrid systems*
- *semiconductor and polymer physics*
- *semiconductor process modeling*
- *sensor and embedded networks sensors*
- *signal processing for nanotechnology*
- *small scale technologies applied to energy infrastructure*
- *social networks*
- *software engineering*
- *software maintenance and evolution*
- *software product-line verification*
- *space-born applications*
- *spatial data structures*

ECE Today VI

- *statistical and sequential signal processing*
- *strained silicon substrates for CMOS devices*
- *subwavelength arrays*
- *superconductivity*
- *suppression of distort*
- *loudspeakers*
- *surface physics*
- *synthesis and characterization of magnetooptic materials*
- *systems biology*
- *theoretical and computational*
- *models to support developments in eddy-current insp*
- *solid*
- *semiconductors*
- *verification*
- *version control and configuration management*
- *scale multicore*
- *voltage references*
- *web engineering*
- *web services*
- *wireless and mobile networks*
- *wireless and sensor network*
- *wireless*
- *Wireless security*
- *wireless sensor networks*
- *x-ray physics*

Biology

Mathematics

Physics

Mechanical Engineering

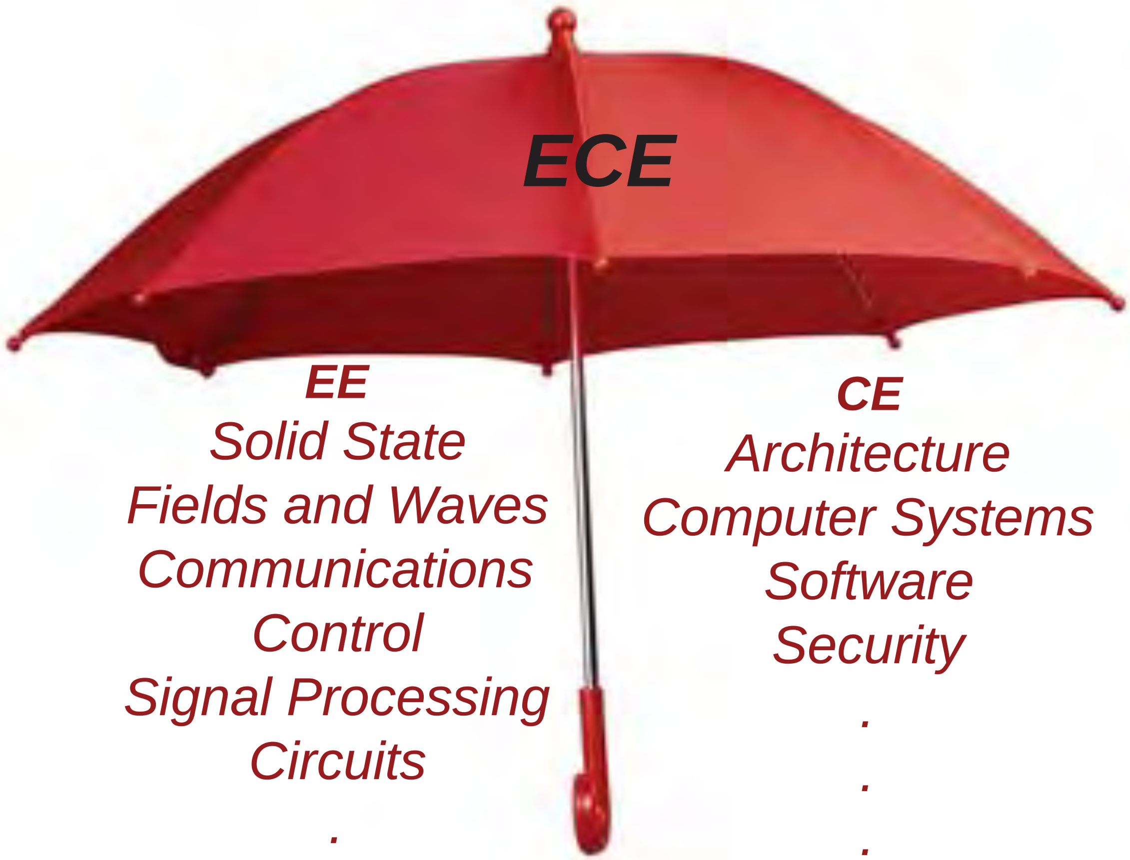
Computer Science

Humanities

Materials Science

Many overlapping “disciplines” …

The “Traditional” View



EE

Solid State
Fields and Waves
Communications
Control
Signal Processing
Circuits
.
.
.

CE

Architecture
Computer Systems
Software
Security
.
.
.

Undergraduate Education: Our View

Nanoscale Systems
Information Storage
Cybersecurity
Computing Performance
Large Scale Complex Systems
Cyber-Physical Systems
Energy Systems
Biomedical Applications

There is no demarcation between EE and CE or indeed between ECE and CS

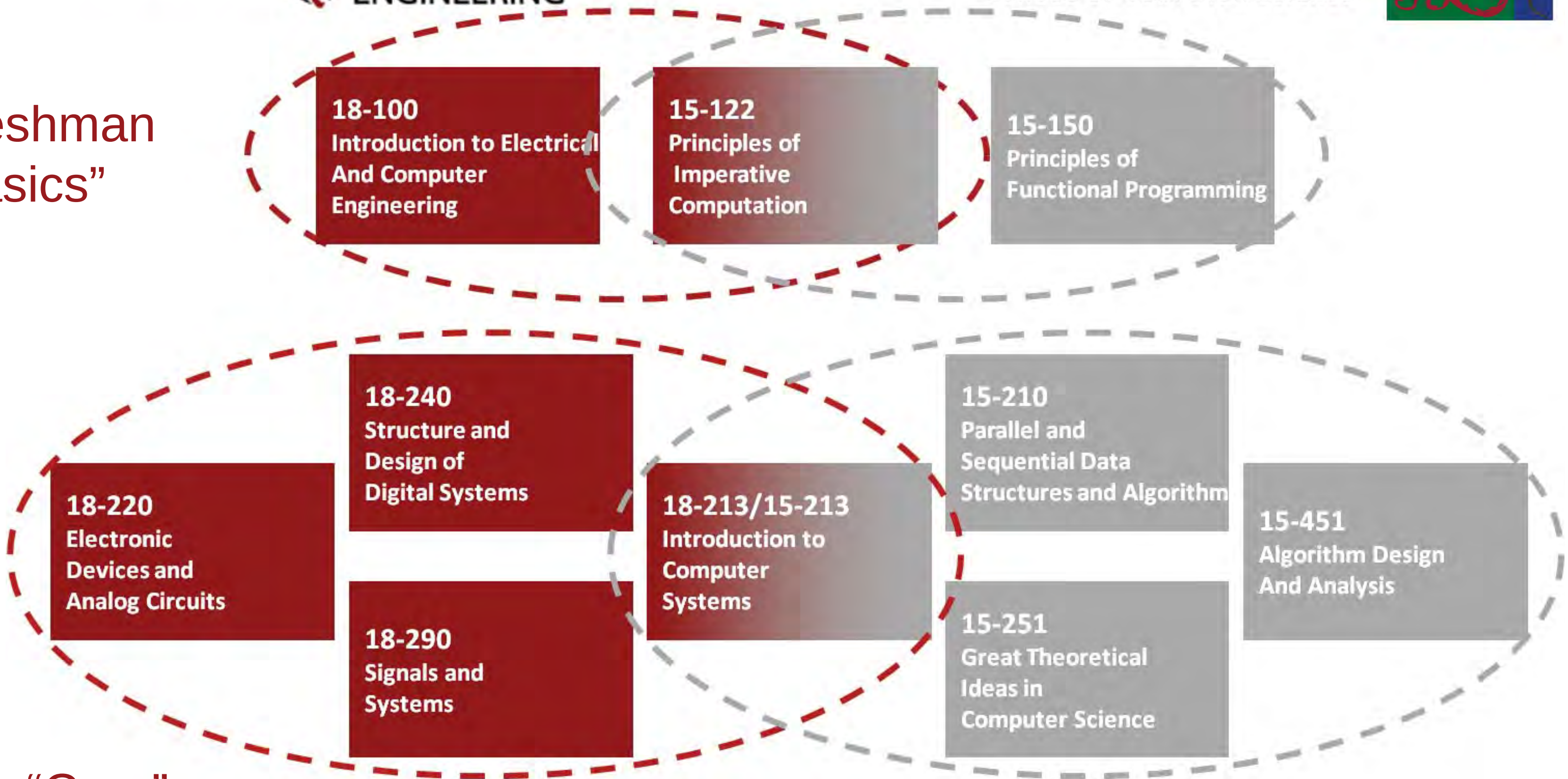
ECE and CS "The Fuzzy Boundary"

Carnegie Mellon ENGINEERING
CARNEGIE INSTITUTE OF TECHNOLOGY

Electrical & Computer ENGINEERING

COMPUTER SCIENCE DEPARTMENT
SCHOOL OF COMPUTER SCIENCE

Freshman "basics"



The "Core"

Motivation to "Eliminate the Boundaries"

- For students who will practice this profession:
  - Students need to see the breadth as well as depth of Electrical and Computer Engineering. They must be prepared to understand that application domains do not easily "fit" into narrowly defined subfields such as "Electrical Engineering" or "Computer Engineering"

- For students who will NOT practice this profession:
  - Electrical and Computer Engineering is the new "liberal arts". Many fields today have aspects of Electrical and Computer Engineering as their underpinning and it is important that practitioners of these fields understands how technology enables and defines their field.

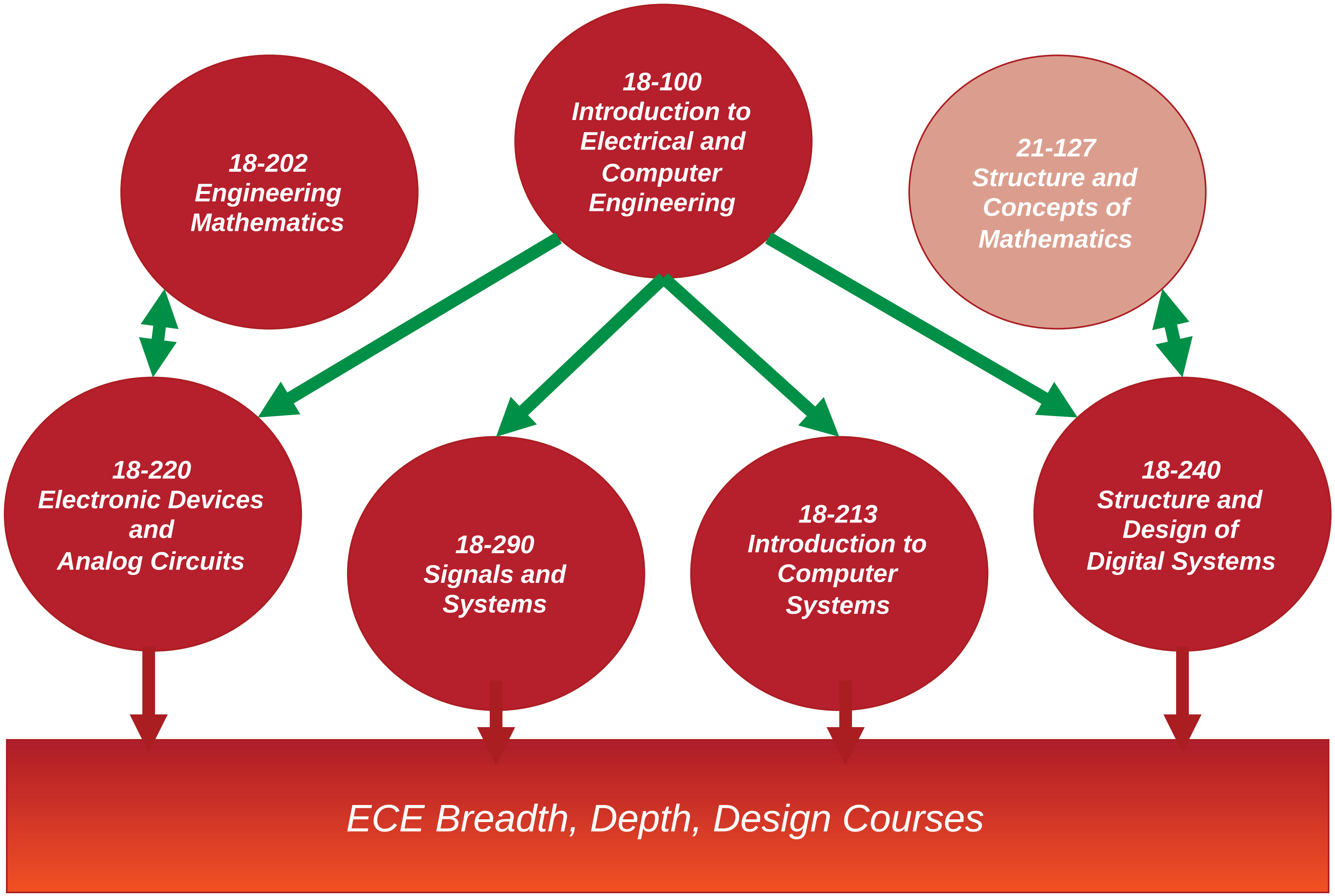
Electrical and Computer Engineering (ECE)

- Despite the large number of "electrical and computer engineering" and similarly named departments at US universities, a recent review of ABET accredited programs showed that only 19 universities offered accredited BS degrees in Electrical and Computer Engineering and 13 in Computer Science and Engineering
- Most universities continue to have separate BS degree programs in Electrical Engineering (297) and Computer Engineering or Computer Systems Engineering (198)
- Our university introduced the BS in ECE as a single degree nearly 20 years ago.

ECE as a Unified Discipline

- The evolution of the field of electrical and computer engineering demands a new breed of ECE graduates with a broad set of competencies that cannot be classified into "EE" and "CE".
- The core requirements should assure students have a foundation in a set of essential concepts and skills for an ECE career.
- The breadth, coverage, depth and capstone design requirements should assure students have a sufficiently rich ECE education.
- The number of free electives should be sufficient to encourage students to:
  - specialize deeply in a particular area of ECE; OR
  - become broadly educated in a number of areas of ECE; OR
  - complement their ECE experience with education in another field (e.g., biomedical engineering, public policy, computer science, business, life sciences, humanities, music, etc.).

ECE “Named” Courses



Intro + Core ECE Courses

- 18-100: Introduction to Electrical and Computer Engineering
  - Provides an overview of the field of ECE and introduces some of the fundamental tools needed to solve problems in this field.

- 18-220: Fundamentals of ECE: Devices and Circuits
  - Provides an introduction to semiconductor devices and circuit analysis with links to digital electronics and signal processing.
- 18-240: Fundamentals of ECE: Structure and Design of Digital Systems
  - Provides a foundation and working knowledge in the application, operation and implementation of digital systems.
- 18-290: Fundamentals of ECE: Signals & Systems
  - Provides mathematical and computational tools for processing signals and information.
- 18-213: Fundamentals of ECE: Introduction to Computer Systems
  - Provides concepts underlying how programs are executed on computer systems

18-200 – Emerging Trends in ECE (1 Unit)

- This class consists of a series of individual lectures given by different faculty members or distinguished alumni. The lectures are designed to serve the following purposes:
  - Introduce to students to the faculty member's research field and the most current world advancements in engineering and technology in that area;
  - Provide students a good understanding of our curriculum structure and the courses in various areas;
  - Present correlations between the present technological developments and our courses for each course area;
  - Introduce new undergraduate courses;
  - Advertise on-campus/off-campus research opportunities for undergraduate students and explain the corresponding research projects;
  - Motivate students with positive presentations on the importance of obtaining education and gaining self-learning ability;
  - Provide basic education on learning and working ethics.
- The class comprises 12 lectures from our own faculty, 2 lectures on learning and working ethics, and 2 lectures from our alumni.

ECE “Breadth” Areas

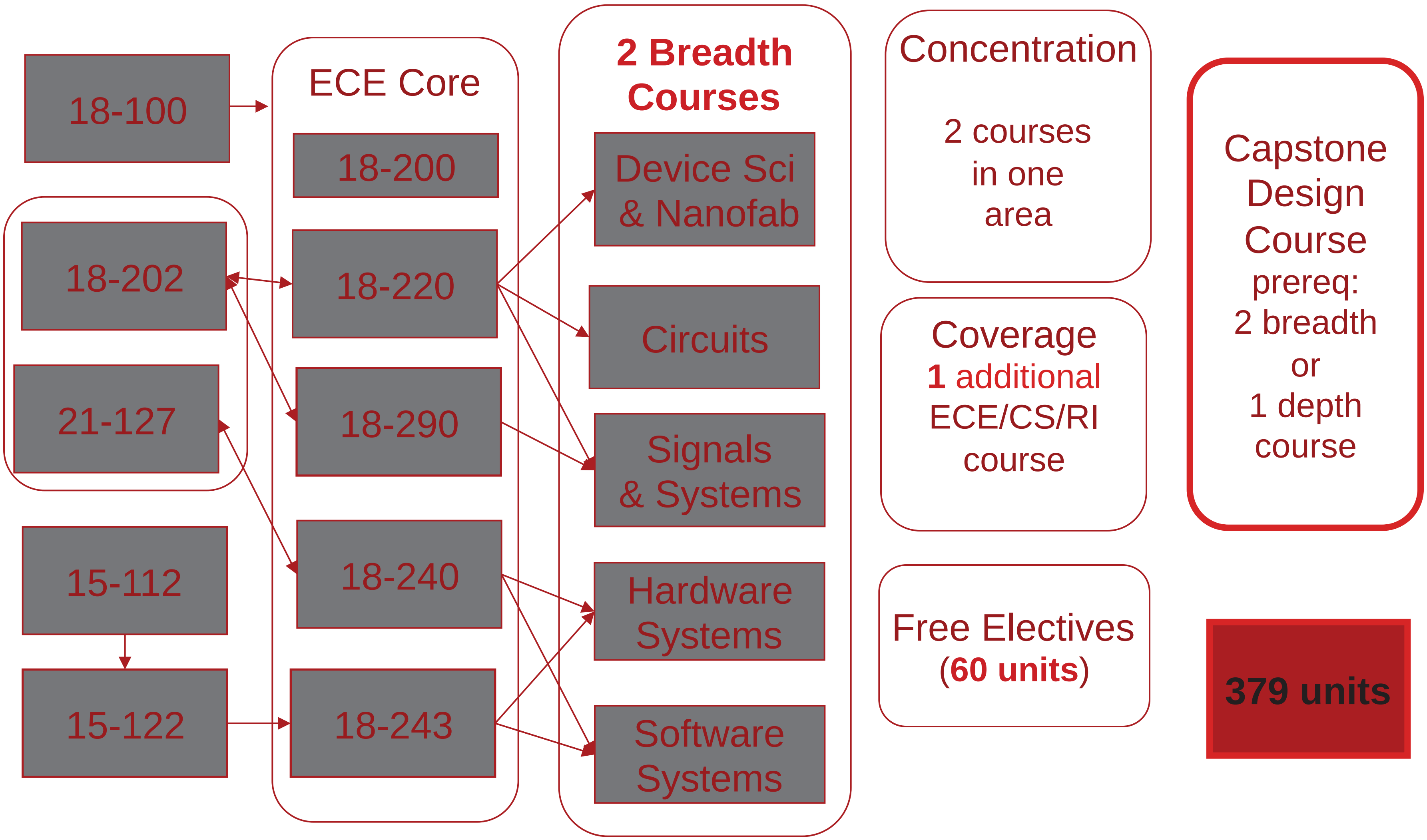
Device Science & Nanofabrication	*Signals And Systems*	*Circuits*	*Hardware Systems*	*Software Systems*
Solid State *Magnetics* *Fields* *Optics* *etc.*	*Signals* *Linear Sys.* *Control* *DSP* *etc.*	*Analog* *Digital* *IC Design* *etc.*	*Logic Design* *Comp. Arch.* *Networks* *etc.*	*Programming* *Data Struct.* *Compilers* *Operating Sys.* *etc.*

“Electrical and Computer Engineering”

Requirements

- *breadth: one course from two different areas*
- *concentration: two courses in one area*
- *coverage: one additional ECE course*
- *capstone: design experience**

ECE Curriculum at Carnegie Mellon



ECE Curriculum – 379 Units

~Four Courses per Semester

Eight Semesters

H&SS	Intro to ECE	Math, Sci, Comp. Prog.	Math, Sci, Comp. Prog.		Fall Freshman
H&SS	Intro to Eng	Math, Sci, Comp. Prog.	Math, Sci, Comp. Prog.		Spring Freshman
H&SS	Fund of ECE	Eng Math	Math, Sci, Comp. Prog.		Fall Sophomore
H&SS	Fund of ECE	Math, Sci, Comp. Prog.	Math, Sci, Comp. Prog.	Math, Sci, Comp. Prog.	Spring Sophomore
H&SS	Fund of ECE	Fund of ECE	Math, Sci, Comp. Prog.		Fall Junior
H&SS	ECE Breadth	ECE Breadth	ECE Depth		Spring Junior
H&SS	ECE Coverage	Free Elective	Free Elective		Fall Senior
H&SS	Free Elective	ECE Capstone	Free Elective	Free Elective	Spring Senior

99. + 75 + 12 + 73 + 60 + 60 = 379 Units

Capstone Design Courses

18-510 Sensor Systems Design

18-513 RF Circuits and Antennas for Wireless Systems

18-525 Integrated Circuit Design Project

18-540 Rapid Prototyping of Computer Systems

18-545 Advanced Digital Design Project

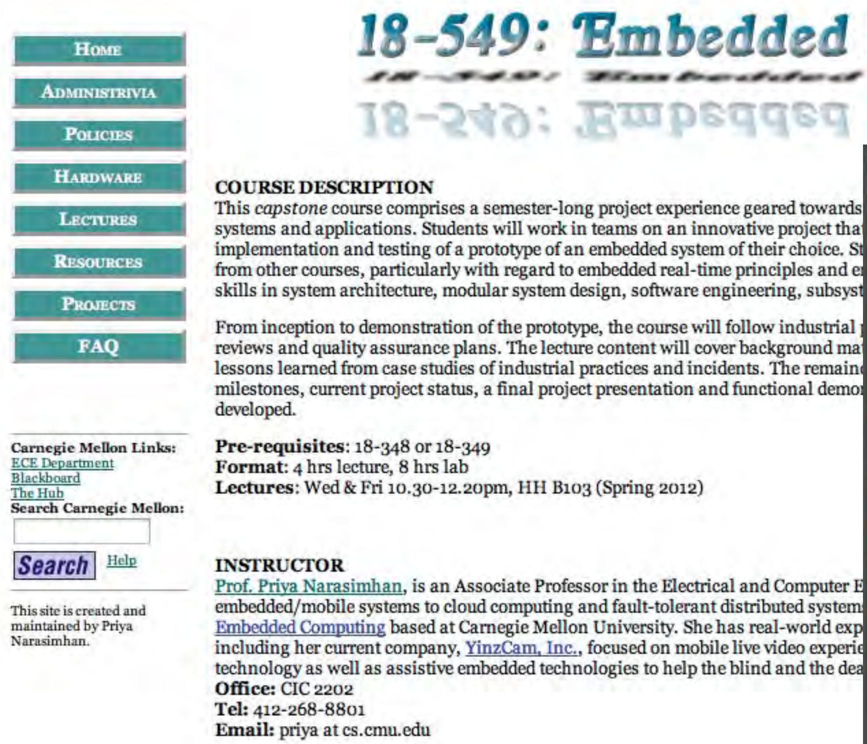
18-549 Embedded Systems Design

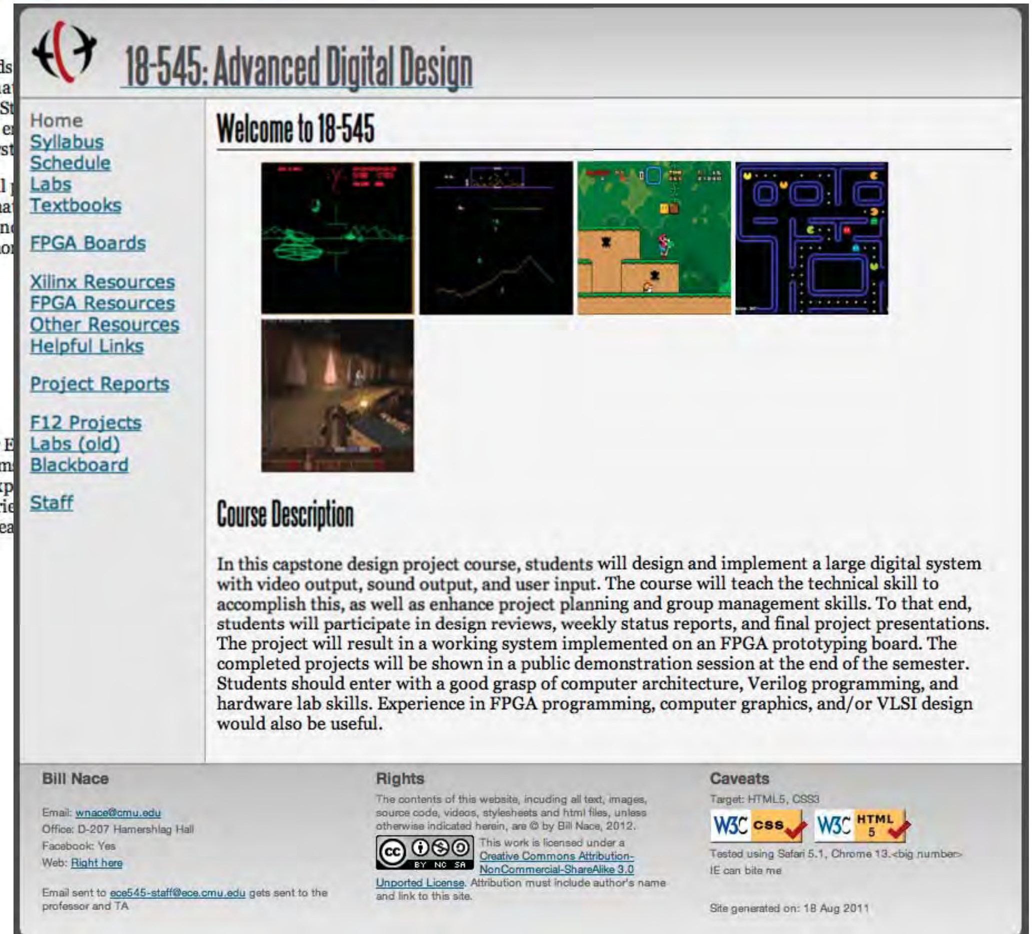
18-551 Digital Communication and Signal Processing Systems Design

18-578 Mechatronic Design

18-587 Electrical Energy Conversion, Control, and Management

Example Projects





Additional Opportunities for Students

Integrated M.S./B.S. Program

- *Open to students with QPA of 3.0 and above*
- *Requirements of "Course Option" M.S.*

Minors, Majors, Double Degrees

- *Double degrees: MORE CREDITS*

Summer Internships

- *Regular on-campus recruiting events*
- *Several international opportunities*

ECE Industry CO-OP

- *Open to juniors with QPA of 3.0 and above*
- *8 month period January to August*
- *Additional summer period (optional)*

Study Abroad

ECE Opportunities

- National Chiao-Tung University & Industrial Internships, Taiwan
- Shanghai Jiao Tong University & Microsoft Research Asia, China
- Ecole Polytechnique Federale de Lausanne, Switzerland
- Instituto Tecnológico y de Estudios Superiores de Monterrey, Mexico

General Education

- Many other opportunities through our Office of International Education

Objection 1: Students Won't Know What to Take

- Students WILL know what to take.
  - Advising is key
  - Content of the core courses is crucial
  - Course descriptions are important
  - The seminar course offered in the Fall of the sophomore year is important

Undergraduate Advising

- Full-time staff
  - Associate Department Head: Prof. James Hoe
  - Educational Program Assistant: Leona Kass-O'Rourke
  - Assistants for Undergraduate Education: Janet Peters, Schauntae Yankasky
  - Director for Student and Alumni Affairs: Susan Farrington
- Faculty advisors
  - For Sophomores (assigned Spring of Freshman year)
- Faculty mentors
  - For Juniors and Seniors (assigned according to interests)
- ECE Website – authoritative source of information
- Electronic media for rapid communication
- Student feedback actively sought
  - ECE Student Advisory Council
  - IEEE Student Chapter, HKN, WinECE
  - Educational Assessment Tool, etc.

Objection 2: Students won’t have to take….

- You mean to tell me that students are not required to take [fill in the blank]?
  - For the “blank” fill in “an important subject I took which I can’t imagine students would graduate without and still be called Electrical and Computer Engineers”
  - Yes. Not all the students have to take every course you took.
  - What they will do in terms of their career will be different from you.
  - What they will do in terms of their careers will be different from each other!
  - Employers will actually have to understand students as individuals

Objection 3: Students will take the “easy” courses.

- No They Won’t
  - Our data show that students take challenging courses and understand why they need to pursue these they are advised well as to what the courses are given good information and have a clear understanding of careers and options
  - Which are the “easy” courses? (For “easy” read not technically deep and of limited value to the student)
  - ….I meant the humanities courses….

Objection 4: Structure can't be accredited!

- Only one ABET accreditation (ECE) not (EE and CE).
- Existence proof that this can be accredited quite successfully
- Requires resources
  - Department Head and Associate Department Head
  - Standing Committee
    - Program Assessment Committee
      - Three Faculty Members
  - Undergraduate Program Staff
    - Educational Program Assistant
    - Assistant for Undergraduate Education
    - Director of Alumni and Student Relations
    - Web team
  - Students
    - Student organizations

Our ABET “Philosophy”

- Guiding Philosophy
  - Are we doing “this” just for ABET or is there independent value?
  - Lowers “cost”
  - Ensures follow through
  - Faculty buy-in
  - Minimizes “ABET-only” activities
- Holistic approach tell the whole story to all our constituencies including ABET not just “ABET-centric” activities

Objection 5: Usually not said out loud…

- What happens if students don't choose to take "my" course?
  - The burden is on the faculty to create courses that attract students and to make clear to the students why they need the course.
  - Students no longer sit in a class because they have been "forced" to be there.
  - There is a very interesting administrative challenge to this.

Conclusion

- Electrical and Computer Engineering is a unified discipline
- ECE is at the center of many important application domains today
- Far too many to expect all students to be trained identically
- This curriculum provides;
  - fundamentals, depth and breadth
  - great flexibility and choice for students
- Course offerings in the specific areas such as security, communications, sensors, energy systems, and more.
- ECE is uniquely positioned to train students for leadership and impact not only in the field of Electrical and Computer Engineering but other career paths as well.

Questions?