



# ECEN 4303: COURSE OVERVIEW

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**Oklahoma State University  
Electrical and Computer Engineering  
ECEN 4303**

Welcome to the Fall 2023 Semester!

# Welcome

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- Honestly, I say welcome!!!
- I am here in hopes of teaching you about the wonderful area of digital integrated circuits.
- I love teaching this class, but teaching is a 2-way street in that I need help if you are getting confused or have trouble.
- I care about each and everyone of you to succeed!



# Contact Information

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(O): (405) 744-9244, (C): (405) 714-3572

Zoom Meeting ID: 915 399 9279 (no password)



Office: 248 Engineering South

- All office hours can be done via Zoom or in person.
- Distance learning, STW and remote students: feel free to contact me anytime.
- We are here to help!

# Course Information

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## **ECEN 4303**

Digital Integrated Circuits and Systems

Monday, Wednesday and Friday: 11:30 AM – 12:20 PM

EN 107

## **Online Material**

Canvas

<http://canvas.okstate.edu>

## **Office Hours (via Zoom)**

Monday and Wednesday: 2:00 PM – 3:30 PM

# Policies

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- I expect that you are all adults and for you to act like it.
- Please be respectful to the instructor, staff, teaching assistants, other students, and other personnel.
  - If you have a problem or complaint, please handle it professionally and/or see me.
  - I promise to listen to your complaint and, if needed, act upon it.
- Attendance is optional, but there is a clear correlation between students who do well and show up to every class.
  - Not showing up for class is a poor excuse in industry and at Oklahoma State University!
  - Plan time accordingly for sleeping, eating, and down time.
- A schedule will be posted with readings/labs that might help you with the lectures.
- I will try to post copies of the lectures I teach on Canvas as a courtesy, but its up to you take notes (in other words, its your responsibility to learn the material and not mine to post notes how to do something).

# Office Hours/Questions

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- Office Hours:
  - Monday & Wednesday from 11:30 AM – 1:00 PM
  - Or, whenever my door is open : I try to keep an open door/Zoom policy.
- If you have a question about homework, projects, assignments, or in general.
  - Please try to post these to piazza (see later), so all can see them.
  - It also gives others a chance to interact.
- If you have a private question, feel free to contact me anytime.
- Last item: do **not** slip assignments under my door!
  - I have this written into my syllabus.
  - I do **not** accept assignments through E-mail or under my door!
  - It must be handed in through Canvas.

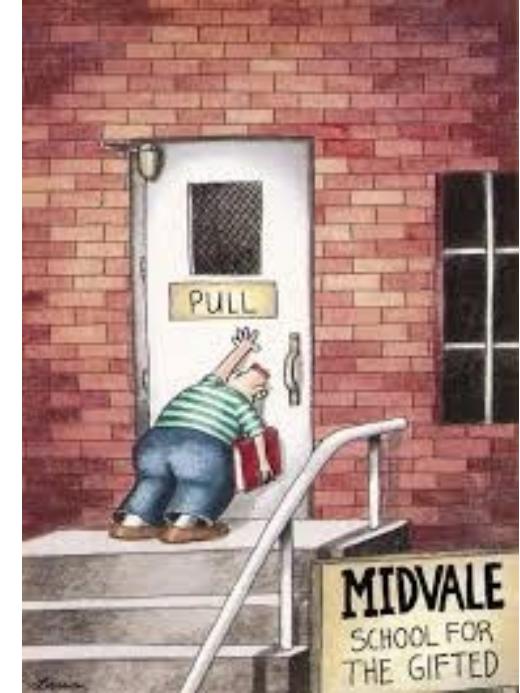
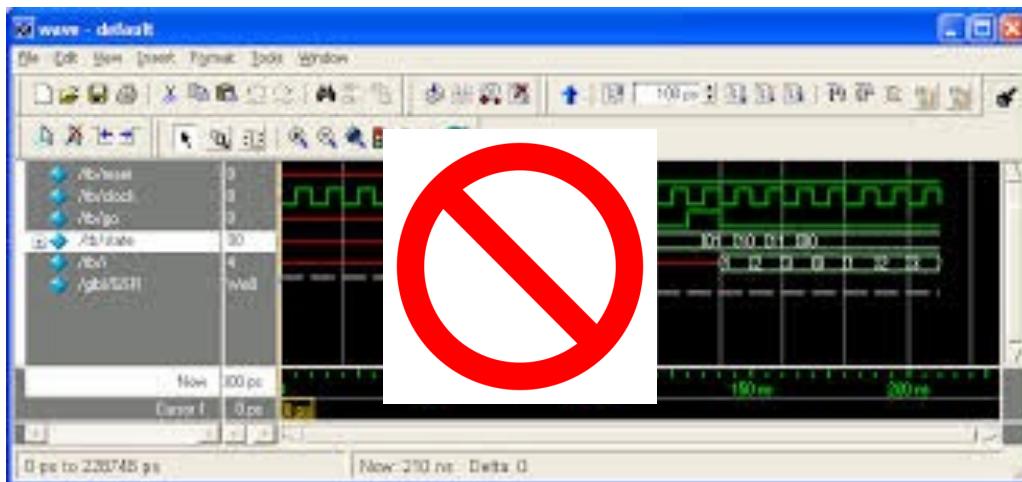
# Software Tools

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- We use lots of tools in this course!
- Tools are going to be buggy and not work all the time.
  - Get used to it! (any professional EE/CpE will tell you that the tools are not going to always work the way you want to)
    - best bet: figure out why things are failing and not just get it to work.
    - Tools are a necessary evil – without them, they will not enable innovation.
  - Be proactive – try some other method!
    - Use your brain to figure out possible solutions.
  - Don't ask me how to fix things – give information on what you did, what you tried, and why it doesn't work after some attempts.
    - Give us information to help you!
    - However, I might be able to suggest what works for me – ask!
    - If you find a solution, help the class out by posting it on our class listing (more later).

# Huh?

- Simulations should be incorporated as PostScript and NO SCREEN SHOTS unless you talk to me first!
  - What is PostScript?
  - Originally invented by Evans & Sutherland and later adopted by Apple and HP.
  - Allows printing to be done easily for any printer (and files!)
- Why?
  - Easy to print out (no toner waste)
  - You should annotate all print outs!!!
  - You can insert into documents (e.g., Word) easily.
  - It is more professional!!!



# Help!

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- This is a different kind of class that uses computers, so I have some helpful hints to get full credit on your assignments:
  - Box your answers; if the question asks for the concentration of atoms in a certain location, please circle your final answer. That way, it's easier for us to correct items.
  - Do not add excessive pages when not needed.
    - 29 pages on why this homework is so laborious is not needed 😊.
  - Use engineering paper to keep things neat or whatever paper you normally use. Engineering paper is useful in that it is easy to center items, since it has a grid.
    - Engineering paper is not required, but a convenience.
    - Why do we use engineering paper?
  - If an assignment involves simulation, please do not print all output (please sparingly print out items to get full credit).
- Try assignments!!!
  - I gave someone a C four years ago for a 79.4%

# Thousand Points of Light

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- I would like to spend 60 seconds to give you my interpretation of Engineering for you.
- What makes up an Engineer?
  - I was in a meeting with one of our esteemed former faculty, Dr. Dan Grischkowsky, who was responding on what he thought engineering was and I think he said it best – “curiosity”.
- But I want to add on to this by stating that you are all thousands of points of light that make up Engineering students at Accreditation Board for Engineering and Technology (ABET) accredited schools.
- You need to focus your thoughts when you are in class, lab, or whatever element related to our program that you are competing with other students at **other** schools.
- Mediocrity or just getting by is not satisfactory!
  - If you need help, ask!
  - I will go above and beyond what I can to help you!
  - You should do what you love to do! Find passion!



# Approved Absences?

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- Every year, I also get students who tell me about missing class due to some event!
  - Extended weekends with family are not approved absences.
  - Traveling to Europe or a conference with an OSU group is not an approved absence.
  - Work-related absences are not approved except in unusual circumstances (e.g., taking of distance learning classes allows those that work full time take this class).
- These are **not** approved absences!!!
  - If you are unsure, please check with me.
  - PLEASE, do **not** tell me you are going to miss class – I really don't want to know why you are making a bad mistake (in my opinion).
- If you are not feeling well, go to the health building and get an approved medical absence (ahead of time, if possible)!!!
  - Contact info on medical absence (yes, I check).
  - Also, try to contact me and I will do all I can to help you make up the material.

# Welcome to Introduction to Digital Electronics

## Circuit Design : ECEN 4303

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- *“Don’t let school get in the way of your education.”*
  - Mark Twain
- Objectives
  - A course for Electrical Engineering, Computer Science, and Computer Engineering students with backgrounds in computers, processors, and circuits to gain exposure and experience in large-scale MOS design.
  - Prerequisites: ECEN 2233, 3314, and familiarity with circuits, logic, and digital system organization. Previous experience with a high-level language and UNIX is also useful.

# Unix

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What if I do not know Unix???????

“... The more I got it through my head that I was going to use Unix, the easier it got to adapt to it. Anyway, Dr. Stine tells me they use it in industry all the time, therefore, there has to be a first time and it ought to be now!”

- That's right - you will be using Unix!! You do not need to know advanced commands. Most of the commands you need to know for this course are easy to learn and use (in fact, many of them are similar to ones used by common Operating Systems like Microsoft Windows and Mac OS X).
- I encourage you to use other tools if it makes it easier for you to develop because you work or live off campus. However, please be aware that the designs must be transferred to our system, compiled and/or executed on our system to receive full credit.
- Again, you must use our tools – apologies, in advance.

# Brief History of GNU/Linux

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- 1985 Free Software Foundation (FSF) founded by Richard Stallman. Along with other programmers creates the tools needed to make a UNIX compatible OS
- 1985 Andy Tannenbaum creates a UNIX like operating system based on System V Unix for the IBM PC & PC/AT computers. It is called MINIX.
- 1989 Richard Stallman releases GPL and GNU software but lacks a free kernel.
- 1991 Building on the concepts in MINIX, Linus Torvalds (Finnish college student) develops Linux along with help from other users on the web.



# What Linux version?

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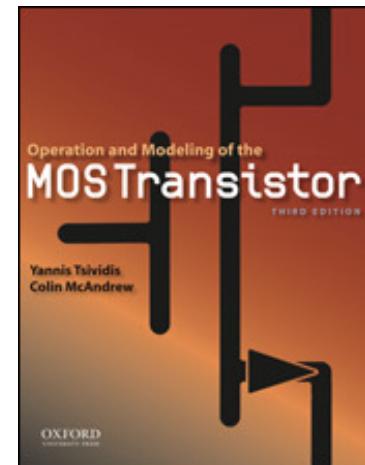
- Strictly speaking Linux refers to the kernel.
- GNU/Linux more accurately describes the Operating System. Linux Kernel combined with GNU utilities and libraries.
- Distribution – GNU/Linux bundled with other applications. Examples Red Hat Linux, Debian, Ubuntu, SuSe, CentOS, etc.
- Distributions can be compiled and maintained by an individual or corporation. Can be small (single USB stick) or span several CD/DVDs.
  - Most versions are controlled over the Internet.
- Most companies (especially for those companies related to this class) rely on versions that are stable and secure.
  - The most common versions that are recommended by the software we use are Red Hat Enterprise Linux (**RHEL**) and SuSe.
  - There are many free versions that are super capable (e.g., Ubuntu, CentOS).

# Textbooks

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- Required (I expect you to purchase the textbook):
  - “Operation and Modeling of the MOS Transistor, 3<sup>rd</sup> Edition”, Y. Tsividis and C. McAndrew, Oxford University Press, 2010, ISBN-10: 0195170156:
  - Amazon Book Cost: \$249 (as of July 20, 2023) ☹
  - Check out AbeBooks: <http://www.abebooks.com>
  - Also Used at Amazon: <http://www.amazon.com>
- I have requested to have this book on reserve in Edmon Low.
- Make sure you have the right textbook!

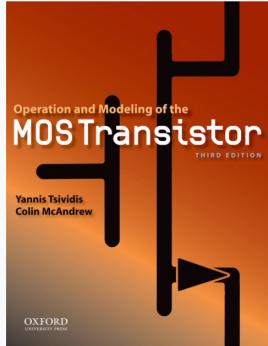
This is the 3<sup>rd</sup> edition – assignments differ by edition and **no credit** will be given for the wrong homework! There is a version on reserve in the library.



# Electronic Textbook

- There is an electronic textbook that seems much cheaper.
- I encourage you to look at this option
  - <https://www.redshelf.com/app/ecom/book/2258849/operation-and-modeling-of-the-mos-transistor-2258849-9780197755044-yannis-tsividis-colin-mcandrew>

**Operation and Modeling of the MOS Transistor**  
Yannis Tsividis; Colin McAndrew  
EISBN13: 9780197755044



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# Grade Distribution

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- Lab Notebook: 5%
- Problem Sets: 20%
- Projects: 50%
- Midterm: 25%



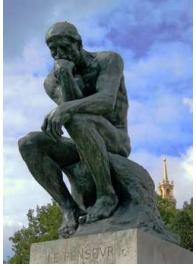
Note: this is a weighted grade; please notify me if you do not understand what this means!

# Schedule

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- I posted a schedule of lectures and their dates on Canvas including the midterm date.
- There are also readings from our current textbook and other textbooks.
- I will try to put the textbook on reserve in the Library for you, but it has been stolen many times so not sure if its in the Library.
- Try to keep alerted of the schedule.





# Thoughts on Homework

- I had the choice whether to give two tests and a final or add more credit to assignments.
- Since the assignments take most of your time, I thought it was:
  - Unfair of me to add the tests when you learn most from the assignments (i.e., if you do them).
  - You do not completely learn the material from tests – you need to put in the time and work.
  - There is still a midterm to test some of your understanding of the concepts, but most of the grade is your assignments.
  - There is no final exam!
- Although I tried to minimize Homework on your grade, it will guarantee to hurt your final grade if you miss them!!
  - So, do **NOT** forget any assignment; that is, try every assignment and hand something in.
  - I had a student five years ago who got a 98% on the midterm grade and a score of 82% on the project, but failed to hand in HW3, HW4, and HW5 and got a C for the course. (This is acceptable if you want a C).



# Homework Upload

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- For homework, you must upload through Canvas.
- This means you will have to either scan your homework or make it into a pdf somehow.
- Great apps for this:
  - <https://acrobat.adobe.com/us/en/mobile/scanner-app.html>
  - <https://www.dropbox.com/features/productivity/doc-scanner-app>
  - Many others...
- Homework is due at midnight the day its due.
  - Make sure you allow time for logging in and uploading and not logging in at 11:59:30 PM.
- I believe there are scanners in Edmon Low (but not 100% sure).
  - You can, of course, use your own scanner or cell phone.

# Assignment 0

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- Homework 0 is posted called “Getting to Know You” that will help me get to know you a little better.
- Don’t forget to post a picture of yourself on the 2<sup>nd</sup> page.
- Please upload to Canvas dropbox by the deadline.
- Pick up some easy points as can be done quickly.
  - Please do not forget as you will lose 50 points!
  - Deadline is posted on assignment and Canvas.
- Homework 1 is also posted!

HW 0 and HW 1



HW0: Due August 28, 2023

HW1: Due September 1, 2023

# Homework and Exam Policy

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- Homework Policy
  - Homework due one week after it has been assigned by midnight unless otherwise specified.
  - Please observe policy on handing in homework – do not E-mail me hw! It will not be accepted via direct E-mail (written into syllabus) !!!!
  - Do not slip HW under my door as I will just throw it away.
  - Absolutely **no** late homework accepted! You are encouraged to keep all of your returned papers until the end of the semester, since I may need them to complete your records.
  - Working together on homework and projects is strongly encouraged, but copying assignments will call for disciplinary action.
  - Homework should be uploaded via PDF to Canvas.
- Exam Policy
  - Makeup exams will not be given, except for extraordinary reasons and only if there is a valid, documented reason that the exam cannot be taken at the scheduled time and I am notified in ADVANCE.
  - The midterm exam date is known in advance (see schedule), please plan accordingly.
  - Any excuse must be corroborated, so please provide documentation (yes, I check).

# Lab Notebook

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What is this crazy lab notebook????

“.....I can’t believe how effective it was to use my lab notebook. Although my lab notebook was messy compared to my friend’s lab notebook, I put little things down that saved me hours of work!!”

- It does not have to be an expensive lab notebook. The bookstore carries lab notebooks; however, they are way **\$\$\$\$\$\$**. It should have permanent pages so they can not be ripped out (not a spiral-bound notebook).
- The lab notebook should contain all preliminary work, daily work, project work, and anything you want to put into it that might help you with your work during this semester.
  - Just shoot me a picture of 1 page at the end of the semester in Canvas.
- How is it graded: Just use it in **some way** and it is easy points.
  - Show me at end of semester or just shoot a picture of it – easy points!
  - Meant to encourage you to write stuff down!



# Electronic Access

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We have some cool ways to get access to help in this class



- slack.com ([vlsifall2023.slack.com](https://vlsifall2023.slack.com))
  - App is available for Google Play and Apple.
  - Please join!
- Text (cell)
  - You are welcome to text me, but please text responsibly.
- Zoom
  - ZoomID: [james.stine@okstate.edu](mailto:james.stine@okstate.edu)
  - Zoom Meeting ID: **915 399 9279** (no password)
  - You do not have to video chat with me, but I will be happy to do that if you want.
- Canvas
  - <http://canvas.okstate.edu>
  - Check regularly!

# The Art of VLSI

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“.....I can definitely see how advantageous it is to purchase colored pencils for this class. It helped me in completing the labs. I didn't have any money to buy them, so I used my cousin's cheapo crayon collection and it worked great.”

- We frequently draw designs in class and lab in color, therefore, it is also advantageous to purchase some cheap colored pencils.
- VLSI is sometimes referred to 90% art and 10% science.
- Who said you couldn't make a career out of coloring!



# Unix Work

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- The ECE department has arranged several servers for us to use.
  - Thank them for this opportunity!
- See Canvas for Unix machines and how to log on.
- We will use a mixture of public-domain and commercial Electronic Design Automation or EDA tools.
  - Some of these commercial tools cost (many) millions of dollars to use.
  - Some tools can be installed on your own computer and others cannot (apologies in advance)!
- We use VNC to connect to the servers and once activated they tend to stay up.
  - It's a good idea to periodically keep backups (e.g., on DropBox)
- The more you learn, the easier it will be for you in the future!

# ECE machines

- ECE machines (8 – about 4-7 users/machine):
  - shire.ecen.okstate.edu
  - gondor.ecen.okstate.edu
  - moria.ecen.okstate.edu
  - angmar.ecen.okstate.edu
  - bree.ece.okstate.edu
  - combe.ecen.okstate.edu
  - dale.ecen.okstate.edu
  - rivendell.ecen.okstate.edu
- Information will be sent to you via Email with user name/password
- Please change your password once you log in.
  - If you change the password on one, it changes it on all of them.
    - Type “passwd” to change the password
    - Ask on slack any questions, provide comments or ask for suggestions!
- Once you get your account, practice!

Use your best  
manners on  
the system!!!

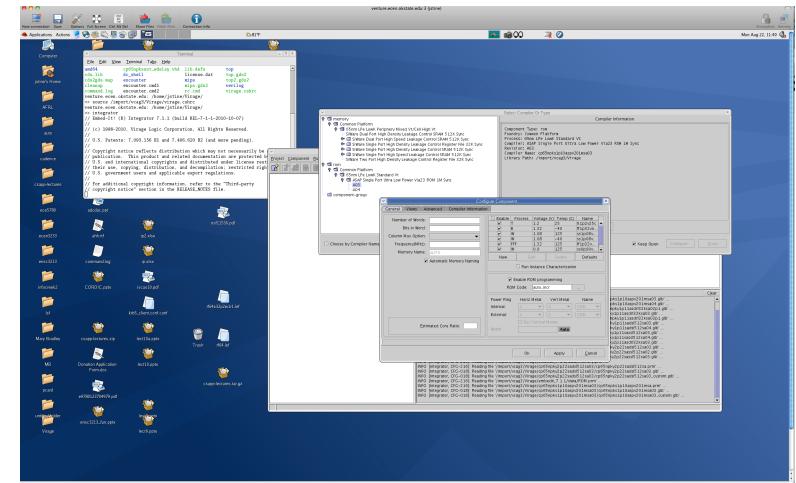
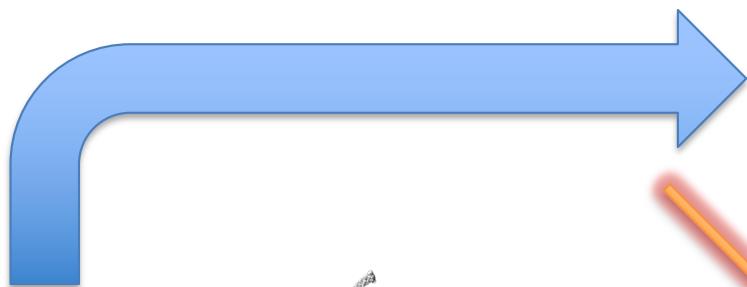


# What is VNC?

- VNC allows you to connect to a machine remotely and work on that system as if you are using a machine in your room (its free).
- <http://www.realvnc.com>
  - Get the viewer (do a Google search)!
  - There's a free app too ☺.



Machine in ES can fail!



ATRC



VNC session stays active  
as long as machine in  
ATRC stays on! 30

procedure posted on canvas

# Class Structure

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Class structure will be as follows (all times approximate):

1. 11:30 PM - 11:35 PM : discussion forum and gripe session
  2. 11:35 PM – 12:20 PM : lecture
- 
- Contact me anytime for classes, but electronic access may be quicker and enable having a trail of breadcrumbs for common errors!
  - Please feel free to ask questions anytime even related to things you have heard in other classes, read in newspaper/magazines, or other relatable items.
  - If something seems hard, there is probably an easier way – ask!

# Courses

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ECEN 4303 is the start of the road if you want to do digital, analog, VLSI, or mixed-signal design in the future.

1. ECE 3233: Digital Logic Design
2. ECE 3314: Electronic Devices
3. ECE 3913: Solid State Devices
4. ECE 4233: High Speed Computer Arithmetic
5. ECE 4243: Computer Architecture
6. ECE 4283: Computer Networks
7. ECE 5263: VLSI Digital System Design
8. ECE 5333: Semiconductor Devices
9. ECE 5363: CMOS Analog Integrated Circuit Design
10. ECE 5253: Advanced High Speed Computer Arithmetic
11. ECE 6253: Advanced Computer Architecture
12. ECE 6263: Advanced VLSI Design and Applications

# Learning Material

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- This course is a combination of “math/science” and actual “hands-on” to give you a physical feel for the science we will cover.
- Problem Sets:
  - Quantitative problems to help you get a sense of the magnitude and a general quantitative feeling.
  - Analytical problems so you can get the general picture for connecting various results together.
- Project will involve taking all the ideas behind the course and will be given at least one month in advance:
  - Addendum\*\*
    - December 8, 2020 @11:59 PM (no exceptions!).
- For any assignment, do **NOT** start late!



# Project

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- I have been doing VLSI for a long time (35+ years) and I really think its going to be revolutionizing devices in the coming 10-20 years.
- Even with challenges with small feature sizes (to be visited soon), designs are incorporating cooler and more innovative ideas.
- Your project will be individualized, and you will work alone.
- If you wait, I guarantee you will not finish regardless how good you think you are or your experience in the past working on projects!

# Project/Assignments

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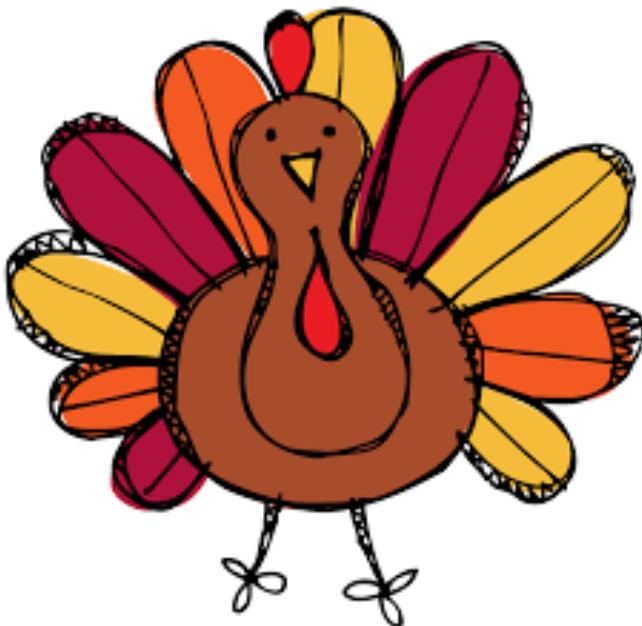
- I love all my OSU students – they are the best and I tell them that every day.
- However, my hands are tied if you do not hand in your project/hw – I have to give you a 0.
  - This is because there is no final in this class.
  - Do not forget to spend time on the report.
- Even if you cannot get something working, hand something in and document as much as you can about what works and what does not.
- I failed 9 students in my class six years ago because they just did not hand in anything (despite my persistent requests) for the project.



"Mr. Osborne, may I be excused? My brain is full."

# Turkey Day Warning

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- Guess what?
  - Thanksgiving falls at the end of November.
- This means you come back, and you must finish up everything.
  - This is going to create more stress for you, and I apologize.
- Its even more complicated for those that have senior design projects.
  - It also means you must have your project completely or 98% done before you go into Thanksgiving to finish up the semester well.
- All I can say is to prepare and plan!
- We are here if you need it.

# Course Contents

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- The following is a rough outline of the course contents:
  - Intuitive overview of the MOSFET and semiconductors
  - 2-terminal MOS structure (gate-body)
  - 3-terminal MOS structure (gate, body, source)
  - 4 terminal MOS structure (the real deal)
  - Modeling for circuit simulation (SPICE and modeling of transistors)
  - Layout and real-life implementation of actual device
- Silicon Run Video (fabrication) – see Edmon Low or <https://siliconrun.com>.



# Dedicating your Time



- 
- Distance learning students have access to the video of the lecture.
  - But, if you do not keep up with the lecture, you are going to be in a boat-load-of trouble. (And I mean a boat-load-of trouble!)
    - Students have a hard time keeping up because of this!
    - If you are taking an Internet-based class, dedicate time during the week for the watching the video consistently.
      - Do **not** miss a lecture!
      - Come ask me questions or post on piazza (you can do it anonymously)!
      - Do not wait!
  - Doing well in life means dedicating your time towards consistent effort!
    - Come to every class if you on campus!
    - Use your mask!

# My Personal Opinion

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- I care deeply about your success and your well being!
  - I want you to **succeed!!**
- Engineering is a gift and I do not have time to argue why you should or should not study engineering.
  - I am paraphrasing, “Oh, I can get by once I get a job and work hard to learn the material” or “I just have to get through this class because its required” – Umm, no you cannot!
- You have a choice, learn the material the correct way or suffer in industry from not knowing what’s going on.
  - I am serious when it comes to engineering – it is a privilege, period!!!!
- I am personally extremely committed to helping students, but its your expectation to find a solution and work on the issues.
  - I cannot find or debug your problems!
- There are no shortcuts!
  - Senior Design is killing me, so I don’t have time for being caught up – Umm, no!
  - Coworkers in industry ostracize or reassign those who do not understand or know how to get things done! (Don’t believe me – find out for yourself)
  - Keep a schedule and get things done early!
  - Work hard!
  - Stay late and get things done!
- I work very hard to make sure assignments are reasonable.

# Hints/Tips

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- Backup often (we do backup weekly). Most of the programs we use, are not super backup friendly.
- Start early on all assignments, hw, and projects especially the final project!
  - **WARNING!** You will probably not be able to finish most assignments the night before its due.
- Do not copy somebody else's work unless you want to experience the fast and furious way to obtain an F!.
  - Be very scared of cheating – it leads nowhere and ultimately hurts you!
  - <http://academicintegrity.okstate.edu>
- If you do not know something when you start working, you tend to get ostracized.
  - There is no benefit of cheating!
  - You either learn the material now or suffer the consequences later!
- If you find something laborious, ask a TA or me if there is an easier way. Almost always, spending 5 minutes of writing a script can save hours and days/months!!
- Ask your peers for hints and tips although keeping in mind that copying is illegal. (Use Social Networking/Piazza).

# Class Notes

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- Class notes will be done via foils or overheads (like this lecture).
  - I often will write stuff down on a notepad to describe what's going on.
  - I may also show you on the Unix system – hopefully, HD video will show up.
- Downloading the notes is still not a substitute for coming to class
- There is strong correlation between students who do well in class, and those that come to class.
- I will do my best to make sure they are up 12 hours in advance before class.
- Although I do not take attendance, I do remember those on campus students that do not show up for class.

# Guides to doing well and getting an A

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- No promises, but these things helped me when I was in school – they may help you.
- Getting good grades is a skill – you can learn them.
  - Many books are available on how to do well in school – try reading one!
  - CEAT and other University-based services/classes are always available.
  - Be curious! Do not just accept what I say!
  - **The University also has a writing-center/excellence center that will be useful for your work in this class.**
- Suggested Rules by Stine (my children and former students can verify them for you):
  1. **Come to every class!!!**
  2. Sit in the front row or close to it, as much as possible.
  3. Take copious notes and rewrite your notes after every class. Yes, rewrite them!
  4. Always try assignments (including reading chapters) – missed assignments are great ways to drop a grade if you are on the border. (I do not curve final grades!)
  5. Study a week before each test – test date is given.
  6. Ask questions!





# WHY STUDY INTEGRATED CIRCUITS?

# Integrated Circuit Technology

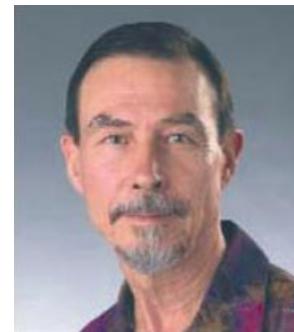
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- Jack Kilby invented the Integrated Circuit (IC) in 1958.
- Before this, the vacuum tube was utilized.
- The ability to put several thousand (nowadays billion) transistors on a chip precludes having to have a thousand chips on a single board.
- Circuits can be characterized differently: low-power, high-speed, radiation-hardened, high-level of integration, high-frequency, and complexity.
- Most of today's electronics are the result of – The invention of the transistor in 1947 by Shockley, Bardeen, and Brattain (Nobel Laureates 1956)
  - The invention of the integrated circuit in 1958 by Jack Kilby (Nobel Laureate 2000)
- IC technology is still growing promising even more revolutionary advances in the future.

# Mead-Conway Revolution

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- This year marks the 45<sup>th</sup> year since we first started teaching this kind of class.
- It was started by Lynn Conway while teaching at MIT.
- You can review the notes Lynn gave during that course:
  - <http://ai.eecs.umich.edu/people/conway/VLSI/VLSIarchive.html>
  - <http://ai.eecs.umich.edu/people/conway/VLSI/MIT78/MIT78.html>
- You can reinvent the future!!!
  - They just decided to teach it!
  - You can succeed in anything you try!



They just decided to make a class when no one had one!



# Transistor Invention

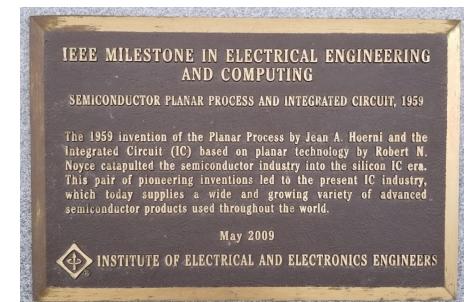
- The transistor was invented in 1947 and it used Germanium.
  - It was terrible at integration (i.e., small sizes and manufacturing it repeatedly)
- A small-town boy from Iowa decided to do something about it!
- He had the mentality, if I cannot make it work, I will do something that will make it work!
  - His name was Robert (Bob) Noyce and grew up on a farm in Iowa building radios, fixing tractors, and flying hand-made airplanes.
  - He graduated from a small College in Iowa and then went to MIT to earn his Ph.D.
- You too can make things happen – you have to believe in yourself, know others, such as myself, believe in **you** and that hard work is the key to making things happen.
- Although Jack Kilby invented the IC and eventually won the Nobel Prize for it, it was Bob Noyce who made it practically realizable and "truly" invented it.
  - Bob Noyce along with 7 others started Intel.





# Never, Ever, Give Up!

- Learn and understand that this industry is a bunch of engineers who never give up!
  - All great engineers should have this trait!!!!!!
- Original transistor was not theoretically fast enough for real-life applications.
  - More importantly, cutting edge ideas were impossible with the limiting speeds found within Germanium transistors.
  - See what Bob Noyce and his group at Fairchild Semiconductor did next (check further reading too).
  - It should be available in Library as I asked them to purchase it!
    - Main STW Library – Edmon Low Creative Studios (1<sup>st</sup> Floor)

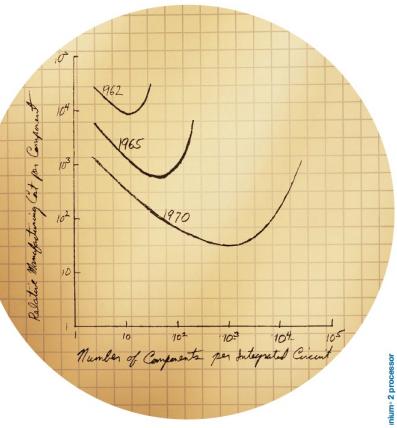


PBS® American Experience: Silicon Valley

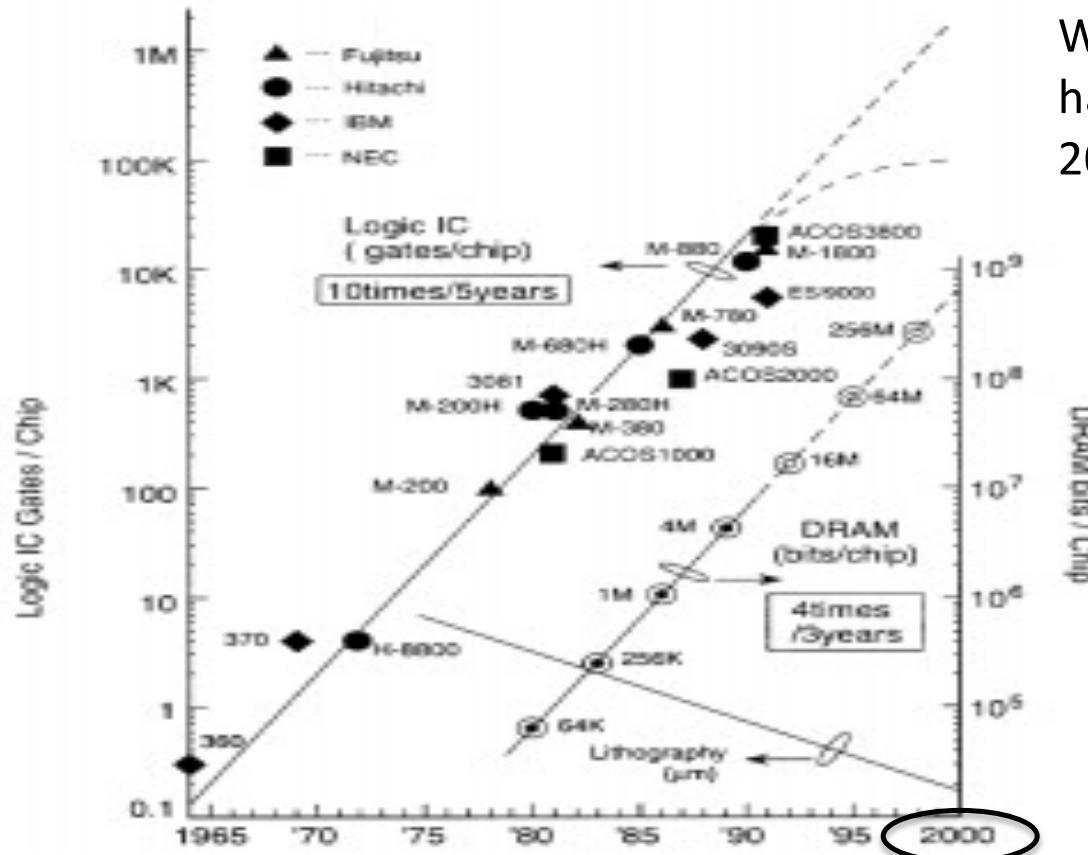
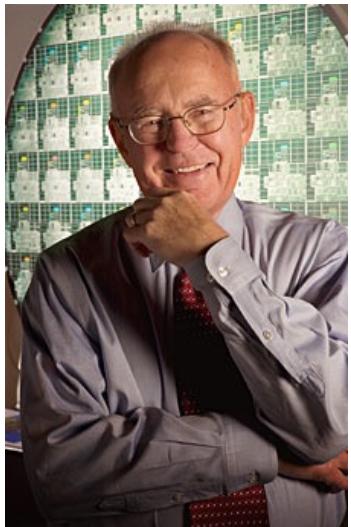
- ✓ <https://www.pbs.org/video/american-experience-silicon-valley/>
- ✓ <https://www.youtube.com/watch?v=LcOoQP7nhI4>

# Advances in Technology

In 1965, Gordon Moore sketched out his prediction of the pace of silicon technology. Decades later, Moore's Law remains true, driven largely by Intel's unparalleled silicon expertise.



[Intel]



Moore's Law : Not a Law but just an observation!!

The number of transistors incorporated in a chip will approximately double every 18-24 months.

What's happening in 2019?



# Applications : Ed Roberts

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- One of OSU's famous graduates Ed Roberts revolutionized the modern Personal Computer (PC)
- He founded MITS which distributed the Altair 8800 that utilized Intel's 8080 microprocessor.
- Bill Gates and Paul Allen joined MITS to develop software and Altair BASIC was Microsoft's first product.
- “Ed was willing to take a chance on us — two young guys interested in computers long before they were commonplace — and we have always been grateful to him,” Bill Gates and Paul Allen quoted in NY Times [April 2, 2010]
  - OSU connection – birthplace of the PC!
  - <https://www.nytimes.com/2010/04/03/business/03roberts.html>



# Wait a second.....

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- Yeah...I just want to take this class, because its required and need to graduate!
  - Just get me **out** of here!
- Note:
  - Learning about how Integrated Circuits behave for digital circuits can be tremendously beneficial...how so?
    - Helps you design digital and analog designs better!
    - You will learn excellent debugging skills, if not already!
    - Helps you understand issues related to wire connections between two points.
    - Can help you understand how light and electricity work together better.
    - Can help you understand roles in software vs. hardware.
    - Can help you understand the importance of software and its use.
    - Understand how Electronic Design Automation (EDA) tools are important to engineering design (e.g., PCB design).
    - Overall...just makes you a better engineer! (IMHO)

# Evolution in Transistor Count

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- Moore's Law or trend states the number of transistors on a chip doubles approximately every 18 months.
- Great News!!! – Die size: 2x every 3 years – Line width: half every 7 years – 0.7x feature size every 3 years – Still holds today – Wafer fabrication decreasing implies cost per chip decreasing – Every 10 years, each gate costs about 1/2 what it did 3 years ago!!!
- Many forecast that we will stop evolving transistors at 5 nm (more on this later).
- Bad News : Boo Hoo!
  - Although the cost of manufacturing IC remains approximately constant, the design cost does not.
  - In addition, productivity is not increasing with time.
  - Cost of chip is growing exponentially with the complexity of the chip
- Good News : Number of designers is still low: jobs, jobs, jobs!!!

# Jobs Transitioning to SoC

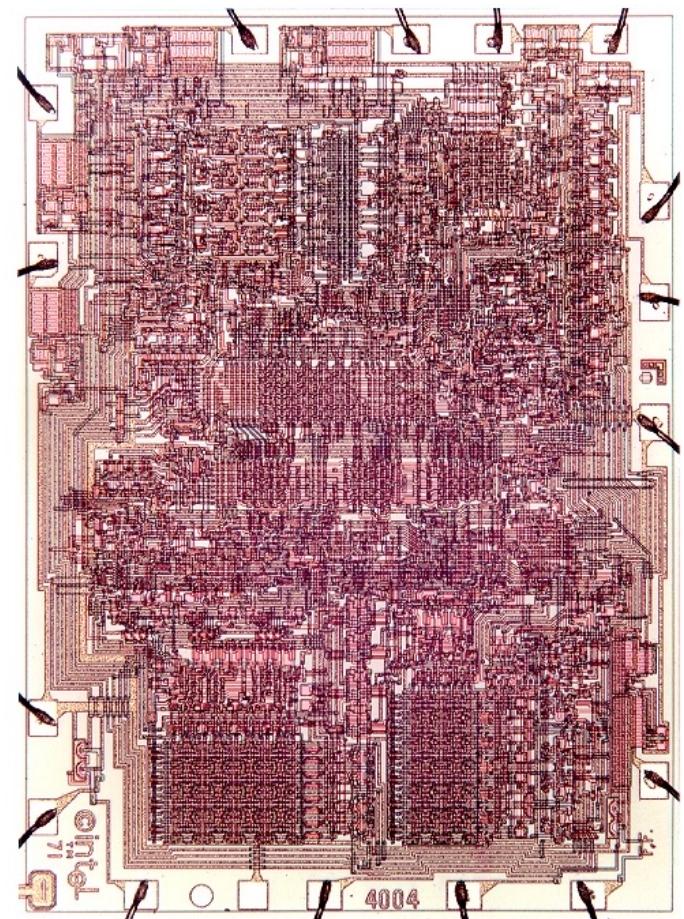
- Jobs are also opening up in mobile and hand-based computing.
  - Chips manufactured that are Application-Specific to specific means
- Apple purchases PA-Semi April 30, 2009
  - Sometimes these companies are called fabless design companies.
- Apple is still opening up many VLSI/digital design positions to build the next generation of devices.

The screenshot shows the homepage of the P.A. Semi website. At the top, there's a navigation bar with links for "ABOUT P.A. SEMI", "PWRficient PROCESSORS", "NEWS & EVENTS", "OUR PARTNERS", and "SUPPORT". The main content area features a large image of a microchip resting on a green leaf with water droplets. Below this image, the text "GREEN COMPUTING" is prominently displayed. To the left of the image, there's a detailed description of P.A. Semi's mission and products, mentioning their focus on "Power to Perform" and "PWRficient™ processors". On the right side of the main content area, there are sections for "News & Press Releases" and "Support", each containing a list of links. At the bottom of the page, there's a footer with links for "Home", "Contact Us", and "Careers", along with a copyright notice: "© 2003 - 2007 P.A. Semi Inc. All rights reserved." and links for "Terms of Use", "Trademarks", and "Disclaimer".



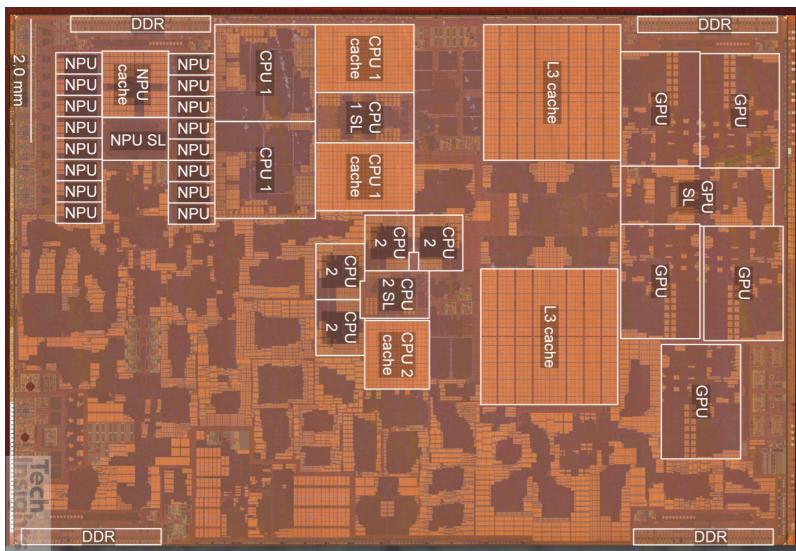
# 4004

- First microprocessor built by Intel (1971)
  - For Busicom calculator
  - Lead architect was Ted Hoff (employee 12).
  - [https://en.wikipedia.org/wiki/Marcian\\_Hoff](https://en.wikipedia.org/wiki/Marcian_Hoff)
- Characteristics
  - 10 µm process
  - 2300 transistors
  - 400 – 800 kHz
  - 4-bit word size
  - 16-pin DIP package
- Masks hand cut from Rubylith
  - Drawn with color pencils
  - 1 metal, 1 poly (jumpers)
  - Diagonal lines (!)



# Contemporary Processors

Apple A15 Bionic (Phones)



6 cores

4 energy efficient 2 GHz

2 high performance 3.2 GHz

32 MiB system cache

Neural engine 15.8 TOP/s

GPU, video, ISP

15 billion transistors in TSMC 5 nm

Intel Alder Lake (Laptop/Desktop)



16 cores

8 energy efficient

8 high performance to 5 GHz

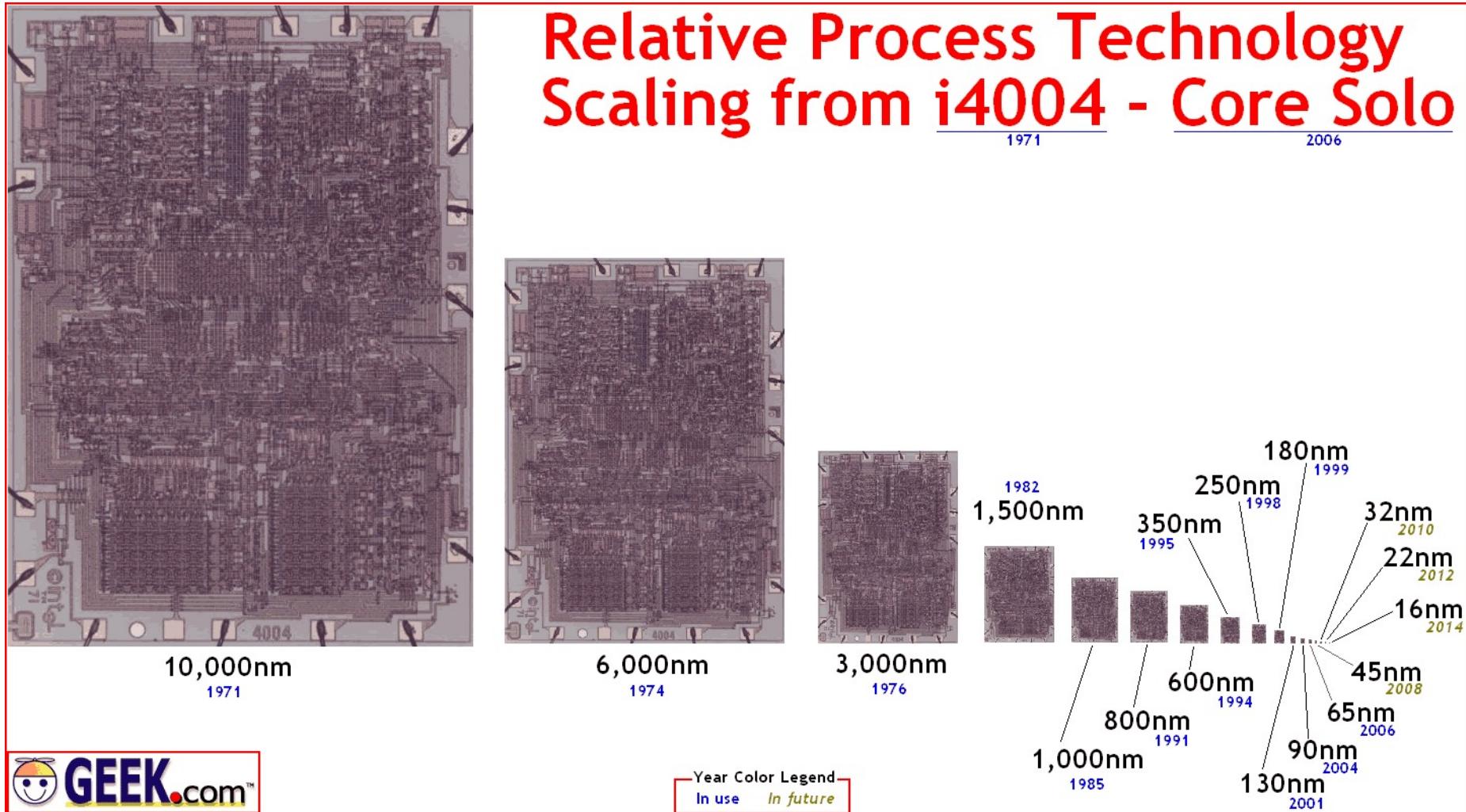
30 MiB L3\$

Graphics & video accelerators

Memory, display, PCI controllers

209 mm<sup>2</sup> die in Intel 7 nm process

# Old → New



# Motivation: The Present

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## Scalable Area, Performance and Battery Life

Mobile Implementation	High-end Wearable
Cortex-A7 MP2 1.2 GHz, 2.25 mm <sup>2</sup>	Cortex-A7 MP2 500 MHz, 1.1 mm <sup>2</sup>



Area calculations based on 28HPM node, 9T

**ARM®**

# Innovate

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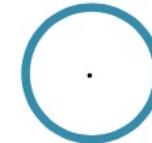
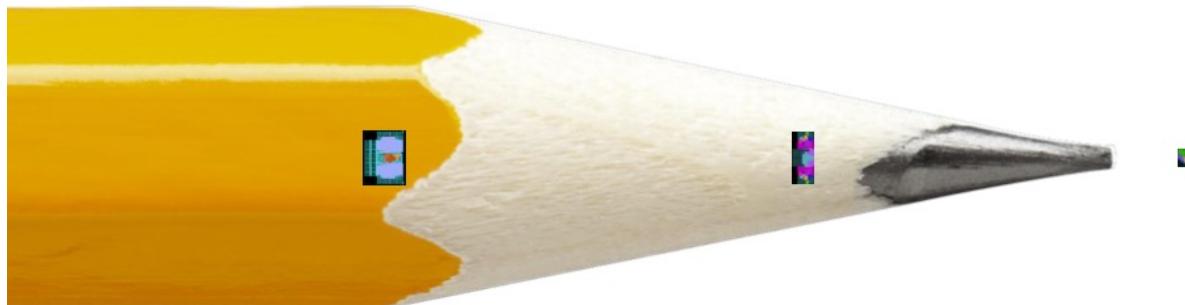
Scalable Area, Performance and Battery Life

Optimized  
Wearable

Cortex-A7 UP  
500MHz, 0.36 mm<sup>2</sup>

Optimized  
IOT

Cortex-M0  
40MHz, 0.05mm<sup>2</sup>



Area based on 28HPM node, 9T, unless otherwise indicated

**ARM®**

# “SEATTLE” SOC OVERVIEW



28nm Process Technology

## Power Efficient Cores

- Up to Eight ARM Cortex-A57 cores
- Up to 4MB shared L2 cache total

## Cache Coherent Network

- Full cache coherency
- 8MB L3 cache
- SMMU: I/O address mapping and protection

## High Performance, Flexible Memory

- Two 64-bit DDR3/4 channels with ECC
- Two DIMMs/channel up to 1866Mhz
- SODIMM, UDIMM, RDIMM support
- Up to 128GB per CPU

## Highly Integrated I/O

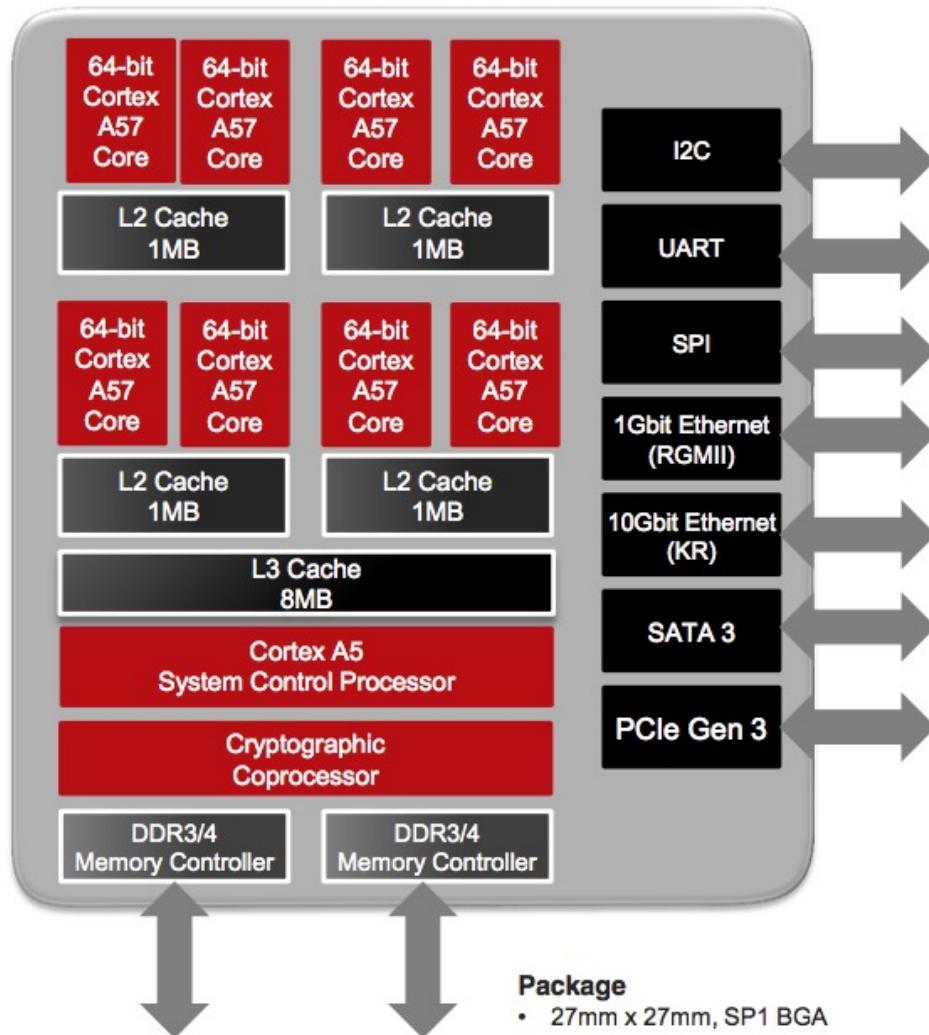
- 8x SATA 3 (6Gb/s) ports
- Two 10GBASE-KR Ethernet ports
- 8 lanes PCI-Express® Gen 3, supports x8, x4, x2

## System Control Processor

- TrustZone® technology for enhanced security
- Dedicated 1GbE system management port (RGMII)
- SPI, UART, I2C interfaces

## Cryptographic Coprocessor

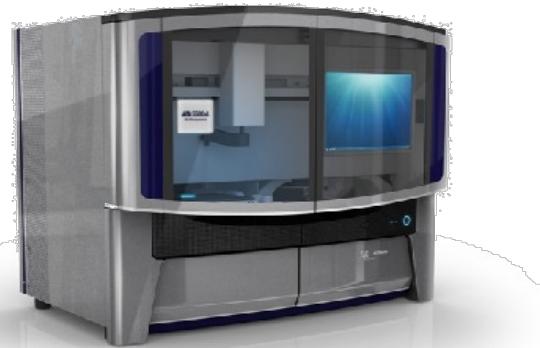
- Separate Cryptographic algorithm engine for offloading encryption, decryption, compression, decompression computations



# Genome Sequencers



Roche/454



AB SOLiD



Illumina HiSeq2000



Pacific Biosciences RS



Ion Torrent PGM

[Onur Mutlu, ETH Zurich]



Ion Torrent Proton



Illumina MiSeq



Oxford Nanopore MinION



Illumina  
NovaSeq  
6000



Complete  
Genomics

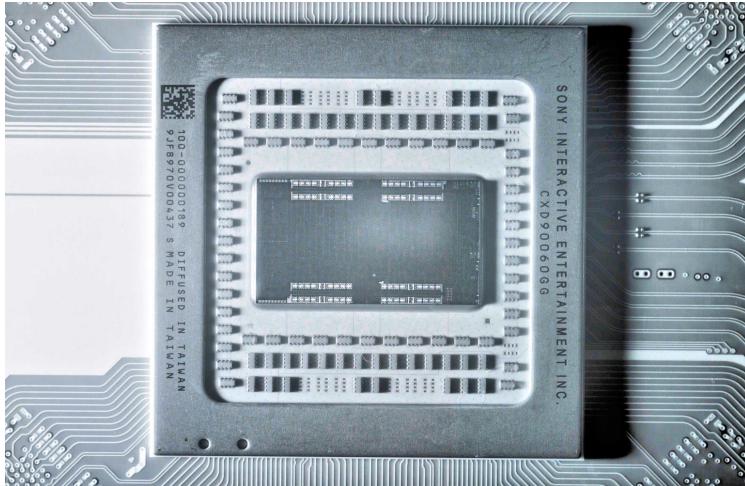
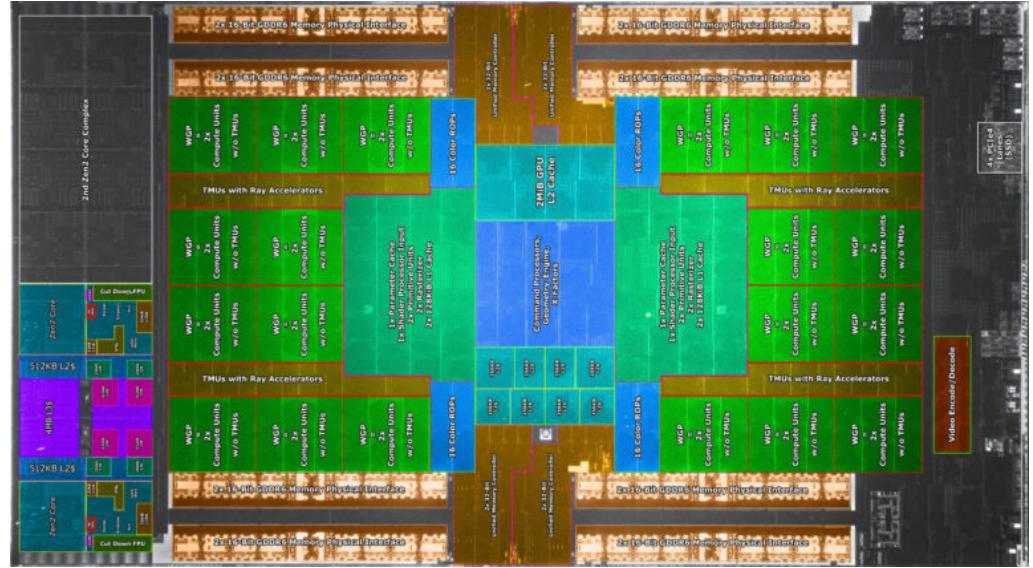


Oxford Nanopore GridION

... and more! All produce data with different properties.

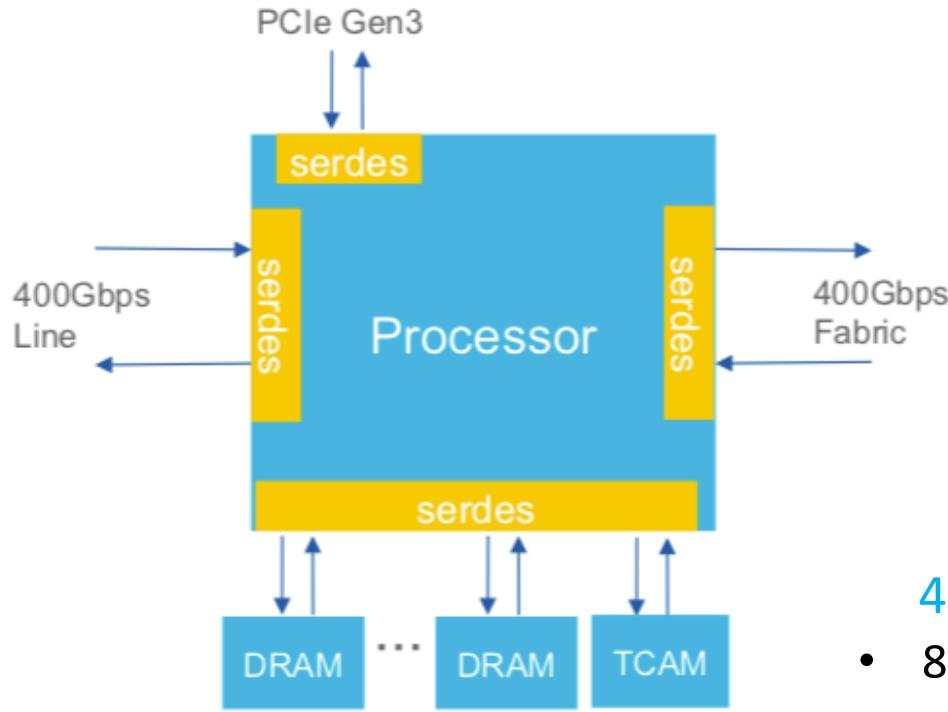
# Sony PS5 SoC

- Features AMD Zen2 core + RDNA2 GPU
- 360.4 mm<sup>2</sup>
- 15.3 billion transistors
- 12-layer substrate
- 52.5 mm x 52.5 BGA package
- Developed in partnership with AMD



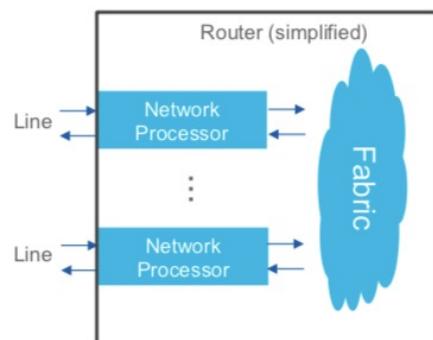
8-cores Zen2 cores are clocked up to 3.5 GHz, while 36 RDNA2 Compute Units can reach a clock speed up to 2.23 GHz.

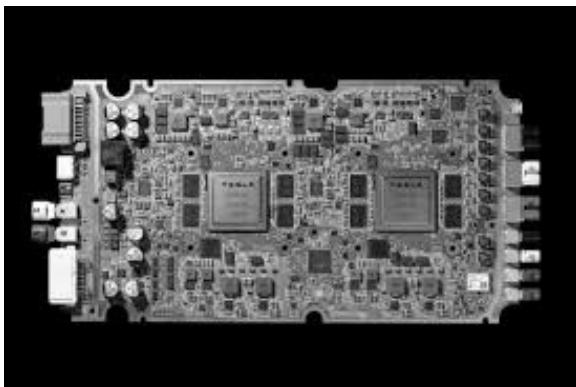
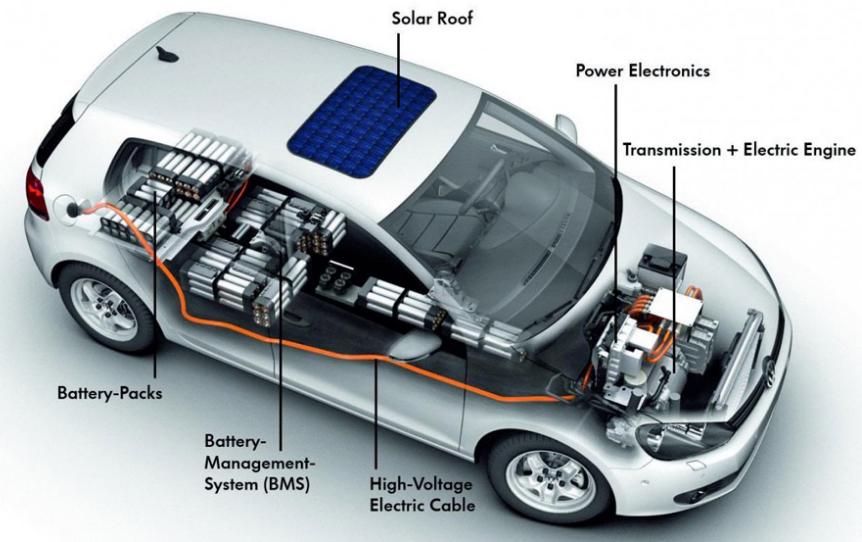




## 400 Gbps Multi-Core Network Processor

- 800Gbps (400Gbps full-duplex) network packet processor
- 672 general purpose processors
- > 6.5Tbps serdes I/O bandwidth
- External DRAM for large data structures and packet buffering
- External TCAM for large data structures
- Integrated Ethernet MACs from 10GE to 100GE
- Integrated traffic manager
- Most logic in 1GHz and 760MHz domains





- Cars are no longer gasoline!
- The potential environmental benefits of electric vehicles are huge.
- If you have not purchased or been in a new car, it is mostly electronics.
- Most cars used a Controller Area Network or CAN bus to communicate with other electronics.
- Many car companies now identify themselves as a technology company.
- How about autonomous vehicles?
- Gasoline cars have electronics too!



# Summary

- $10^4$  increase in transistor count, clock frequency over 3 decades!

Processor	Year	Feature Size ( $\mu\text{m}$ )	Transistors	Frequency (MHz)	Word Size	Power (W)	Cache (L1 / L2 / L3)	Package
4004	1971	10	2.3k	0.75	4	0.5	none	16-pin DIP
8008	1972	10	3.5k	0.5–0.8	8	0.5	none	18-pin DIP
8080	1974	6	6k	2	8	0.5	none	40-pin DIP
8086	1978	3	29k	5–10	16	2	none	40-pin DIP
80286	1982	1.5	134k	6–12	16	3	none	68-pin PGA
Intel386	1985	1.5–1.0	275k	16–25	32	1–1.5	none	100-pin PGA
Intel486	1989	1–0.6	1.2M	25–100	32	0.3–2.5	8K	168-pin PGA
Pentium	1993	0.8–0.35	3.2–4.5M	60–300	32	8–17	16K	296-pin PGA
Pentium Pro	1995	0.6–0.35	5.5M	166–200	32	29–47	16K / 256K+	387-pin MCM PGA
Pentium II	1997	0.35–0.25	7.5M	233–450	32	17–43	32K / 256K+	242-pin SECC
Pentium III	1999	0.25–0.18	9.5–28M	450–1000	32	14–44	32K / 512K	330-pin SECC2
Pentium 4	2000	180–65 nm	42–178M	1400–3800	32/64	21–115	20K+ / 256K+	478-pin PGA
Pentium M	2003	130–90 nm	77–140M	1300–2130	32	5–27	64K / 1M	479-pin FCBGA
Core	2006	65 nm	152M	1000–1860	32	6–31	64K / 2M	479-pin FCBGA
Core 2 Duo	2006	65–45 nm	167–410M	1060–3160	32/64	10–65	64K / 4M+	775-pin LGA
Core i7	2008	45 nm	731M	2660–3330	32/64	45–130	64K / 256K / 8M	1366-pin LGA
Atom	2008	45 nm	47M	800–1860	32/64	1.4–13	56K / 512K+	441-pin FCBGA

[Harris]



“Carpe Diem: Seize the day”

Let's do something amazing!

# ECEN 4303



- Hope it will be a fun course!
- Give you real-life experience using practical skills, but still give you the theory you need to understand digital circuits better!
- We are here to help and care about your success....so, please ask for it!
- I hope you will take the journey with us even if you are required to take this class!
- Have a great semester!
- Go Pokes!

Make a difference now!

