Explaining MIT's Impact on Shannon Theory

Chapter 3 of *Digitizing Communications*
www.JoelWest.org/DC

Joel West
May 22, 2007

SAN JOSE STATE UNIVERSITY
powering silicon valley

Outline

- Research program & motivation
- Shannon theory
  - Application to space communications
- MIT's Golden Age of Information Theory
  - Possible explanations: institutions, people
- Unresolved questions
- Discussion

How We Got Here

Joel West (PhD, UC Irvine, 2000)

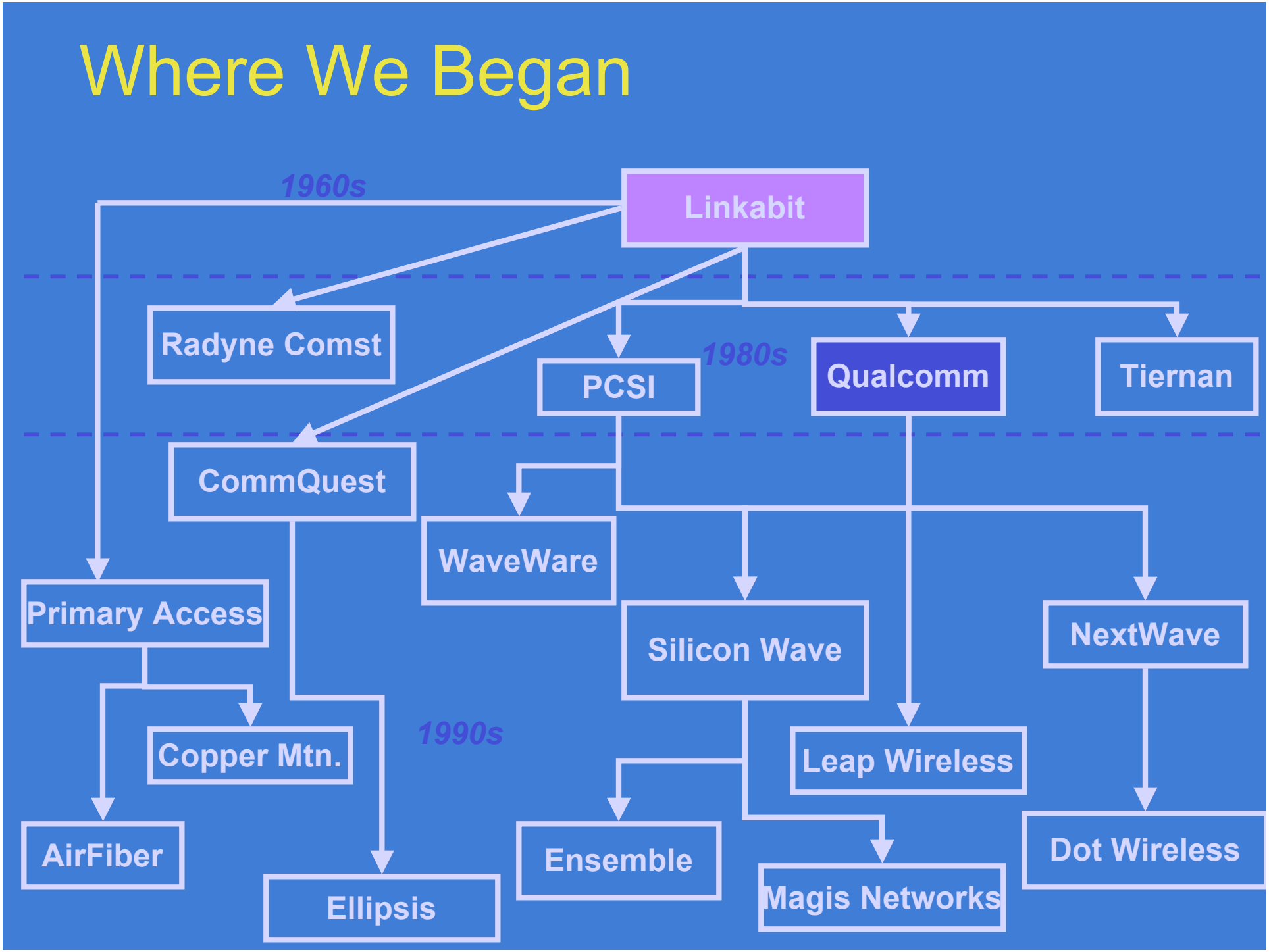
- 1987-2002: PC software entrepreneur
- 1994-2000: research on PC standards
- 1996-1998 planned diss. on 1G cellphone launch in Japan (’79), Sweden (’81), US (’83)
- 2000-2002: Qualcomm case (ECCH.org)

Caroline Simard (PhD, Stanford, 2004)

- Bachelor’s, master’s in communications
- Stanford study w/François Bar, Woody Powell
- 2001-2004: diss on 240+ San Diego wireless startups

2002: met at San Diego telecom industry event

Where We Began



Which Leads Us To

Andrew (& Erna) Viterbi

viterbi.usc.edu

Irwin (& Joan) Jacobs

jacobsschool.ucsd.edu

Jacobs & Viterbi Story

Irwin Jacobs and Andrew Viterbi:

- Attend MIT (Viterbi S.B.,S.M.; Jacobs S.M., Sc.D.)
- Get jobs as college professors
  - Jacobs: MIT 1959-1966, UCSD 1966-1971
  - Viterbi: UCLA 1963-1973
- Start Linkabit in 1968 in Los Angels
  - one-day a week consulting company
  - move it to San Diego in 1971, Jacobs starts full-time
  - both quit their university jobs
  - sell Linkabit in 1980, continue to work until 1985
- Exploding seedpod of entrepreneurship, 1985-2000

Qualcomm

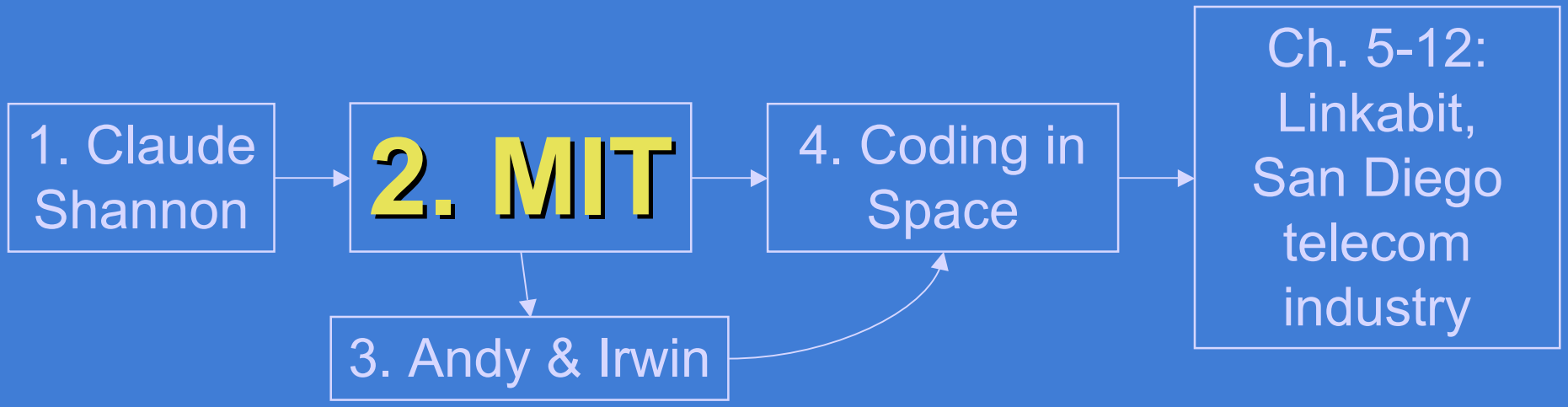
- Founded 1985 by Jacobs, Viterbi, 5 others
  - 1st prod.: Omnitracs satellite-based truck tracking
- IPO in 1991
- Known for inventing CDMA mobile phone IPR
  - Launch in 1995, adopted US, Korea, Japan, H.K.
  - Essential IPR for W-CDMA
- Today: $75 billion market cap
  - Patent licensing and mobile phone chips
  - 2006: $7.5 billion revenues, 33% net income
  - Joined Fortune 500 in 1999, today #317

Research Program

- Academic book (5/12 chaps in early drafts)
  - Target completion date: summer 2008
- Transformation of US wireless communication industry from analog to digital from 1960-2000
  - Key technology: Shannon (1948) theory
  - Empirical focus: startups that create the San Diego telecom industry (and their antecedents)
  - Theoretical focus: technology commercialization and engineering entrepreneurship
- 3-4 academic papers

Plan for the Book

Working title: *Digitizing Communications From MIT to Qualcomm*



Application of Shannon Theory to NASA Communications

Discontinuity: Shannon Theory

- Claude Shannon goes to MIT then Bell Labs
- In 1948, he publishes “A mathematical theory of communication” in the *Bell Tel. Lab. Journal*
  - This launches what is called “Shannon Theory” or “information theory”
- During the 1950s-1960s, an important area of research is on channel coding
  - Shannon’s coding theorem is ideally suited for deep space communications

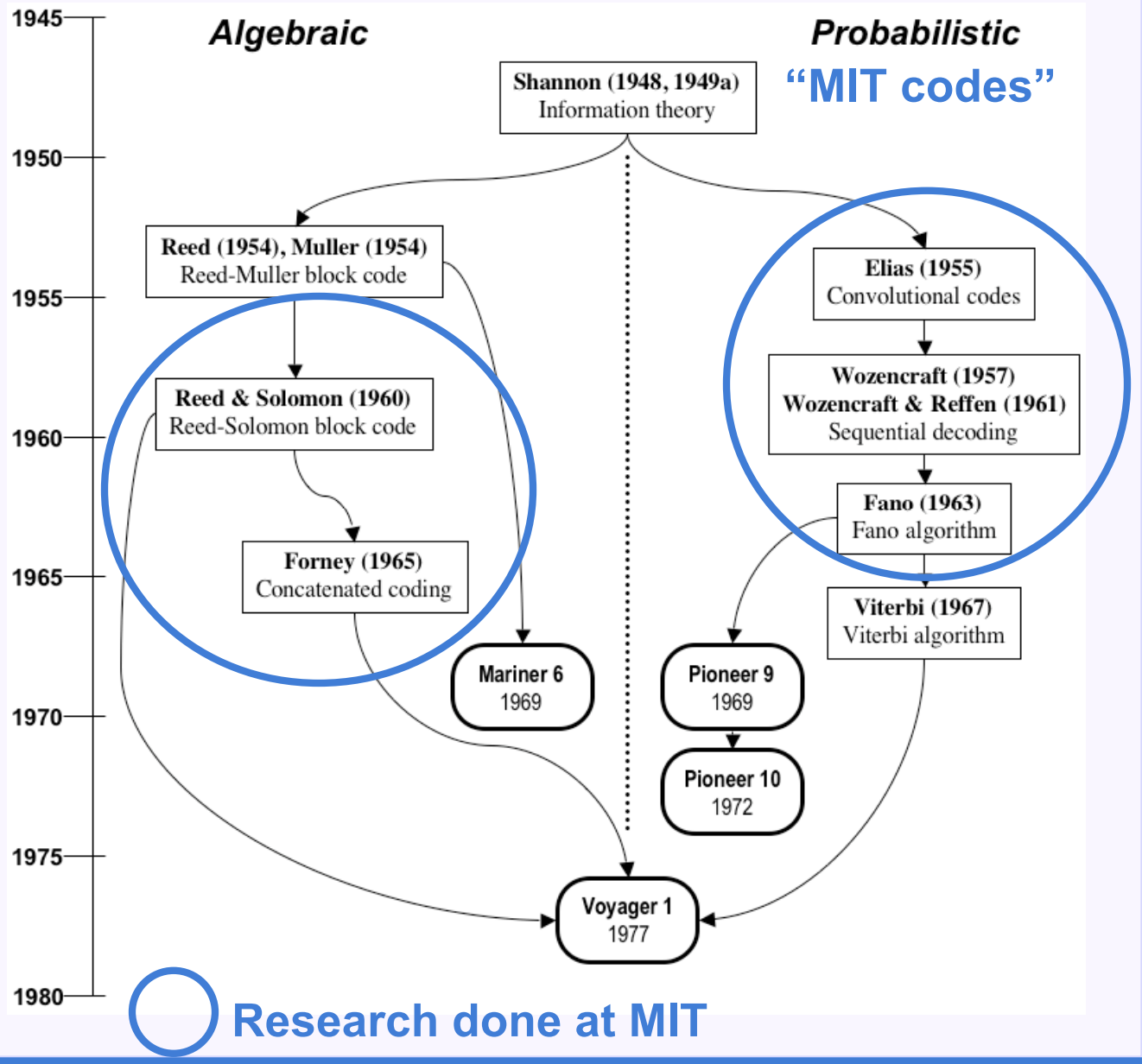
Milestones in Channel Coding Theory

- 1950s: Block codes
  - Reed-Solomon (1960) is the best
- 1960s: Convolutional codes (1960s)
  - Sequential decoding (Wozencraft, 1957; Fano, 1963)
  - Viterbi decoding (Viterbi 1967)
- 1970s: Concatenating block and convolutional codes (Viterbi et al 1971)
- 1990s: “turbo” codes

Coding in Space

- NASA needs to send data from outer planets
  - A billion miles away — $1/d^2$ attenuation
  - Long missions, without solar power available; limited transmitter power (8-25 watts)
- Reached limits on antenna size
  - 70m ground satellite dish cost $200m each
  - Spacecraft dish limited by booster diameter
- Channel coding provides the answer
  - MIT alumni boost SNR by 9 dB from 1968-1989
  - Forney & Massey provide first 6 dB
  - Viterbi & Linkabit provide last 3 dB

Coding in NASA Probes



MIT's Golden Age of Information Theory

Today's Claim

- MIT's "Golden Age" of information theory extended from ca. 1950-1965
  - Accumulation of talent
  - Contributions made at MIT
- The peak was 1959-1962
- A concentration never seen at any other institution, before or since

MIT's Impact During Golden Age

- Largest info theory breakthroughs
  - As measured by IEEE Shannon prize
- Steady stream of graduates
  - To both faculty and industry jobs
- The most important textbooks
  - Codify tacit knowledge
  - Disseminate that knowledge
  - Define the direction of the field

MIT's Shannon Award Winners

Date	Name	MIT Ties
1973	**Claude E. Shannon**	**SM, PhD, faculty**
1976	**Robert M. Fano**	**PhD, faculty**
1977	**Peter Elias**	**SB, faculty**
1981	W. Wesley Peterson	Visiting associate professor
1982	Irving S. Reed	Lincoln Lab
1983	**Robert G. Gallager**	**SM, ScD, faculty**
1986	**William L Root**	**SM, PhD, Lincoln Lab**
1988	**James L. Massey**	**SM, PhD**
1991	Andrew J. Viterbi	SB, SM
1993	**Elwyn R. Berlekamp**	**SB, SM, PhD**
1995	**G. David Forney**	**SM, ScD**
1997	**Jacob Ziv**	**ScD**
2000	**Thomas Kailath**	**SM, ScD**
2005	Richard Blahut	SB

Courses (1965)

Course	Title†	Begun	Instructor	Textbook
6.311	Principles of Communication	Fall 1952	Elias, Wozencraft, others	Wozencraft & Jacobs (1965)
6.571	Statistical Theory of Communication	< 1951	Lee	Lee (1960)
6.572	Statistical Theory of Nonlinear Systems	Fall 1961	Lee	Wiener (1958)
6.573	Statistical Theory of Noise and Modulation	Fall 1951	Wiesner. Siebert, Davenport	Davenport & Root (1958)

Courses (1965)

Course	Title†	Begun	Instructor	Textbook
6.574	Transmission of Information	Spring 1951	Fano, Gallager	Fano (1961); Gallager (1968)
6.575	Advanced Topics in Information Theory	1956	*various*	Peterson (1961)
6.576	Statistical Theory of Detection, Estimation and Modulation	Fall 1961	Siebert, Van Trees, others	Van Trees (1968; 1971a, 1971b, 2001)
6.577	Modulation Theory and Systems	Before 1951	Baghdady, Wozencraft	n/a

Why at MIT?

Possible explanations:

- Institutions
  - RadLab/RLE
  - MIT dominance in EE
  - Positive feedback of success:
    - Attract good PhD students
    - Hire own PhD students
- People
  - Shannon
  - Fano & Elias
  - Wiener/Lee?

Institutions

Institutional Context

- Applied research @ MIT
  - William Barton Rogers' original goals
  - Rise of research in MIT engineering
- Rad Lab: can we overstate its impact?
- Research Laboratory of Electronics

Applied Research

- Rogers wants applied research with scientific principles:
  - "When thus instructed in applied science, the … engineer clearly comprehends the agencies of the materials and instruments with which he works, and is, therefore, saved from the disasters of blind experiment"

Course VI "Research"

- How much research in Course VI before 1940?
  - 10/113 MIT doctorates 1865-1925
  - 56/928 through 1945
  - Many faculty in 1950 have SB or SM

Radiation Laboratory

- Founded 1940 *at* but not *in* MIT
- Brings MIT lots of resources
  - Staff of 4,000 effectively doubles MIT
  - MIT gets $117m from 1941-1945
    - Equivalent to $1.4 billion today
    - Army/Navy spend $2 billion (WW II) on equipment
  - MIT learns to use external research funding
- Brings lots of talent
  - 8 future Nobel Prize scientists
  - Future MIT faculty: Wiesner, Fano

RLE

Research Laboratory of Electronics:

- Conduit for DoD money
- Mainly used for public, pure research
- Seem to have almost no strings
- An institution or a confederation?

People

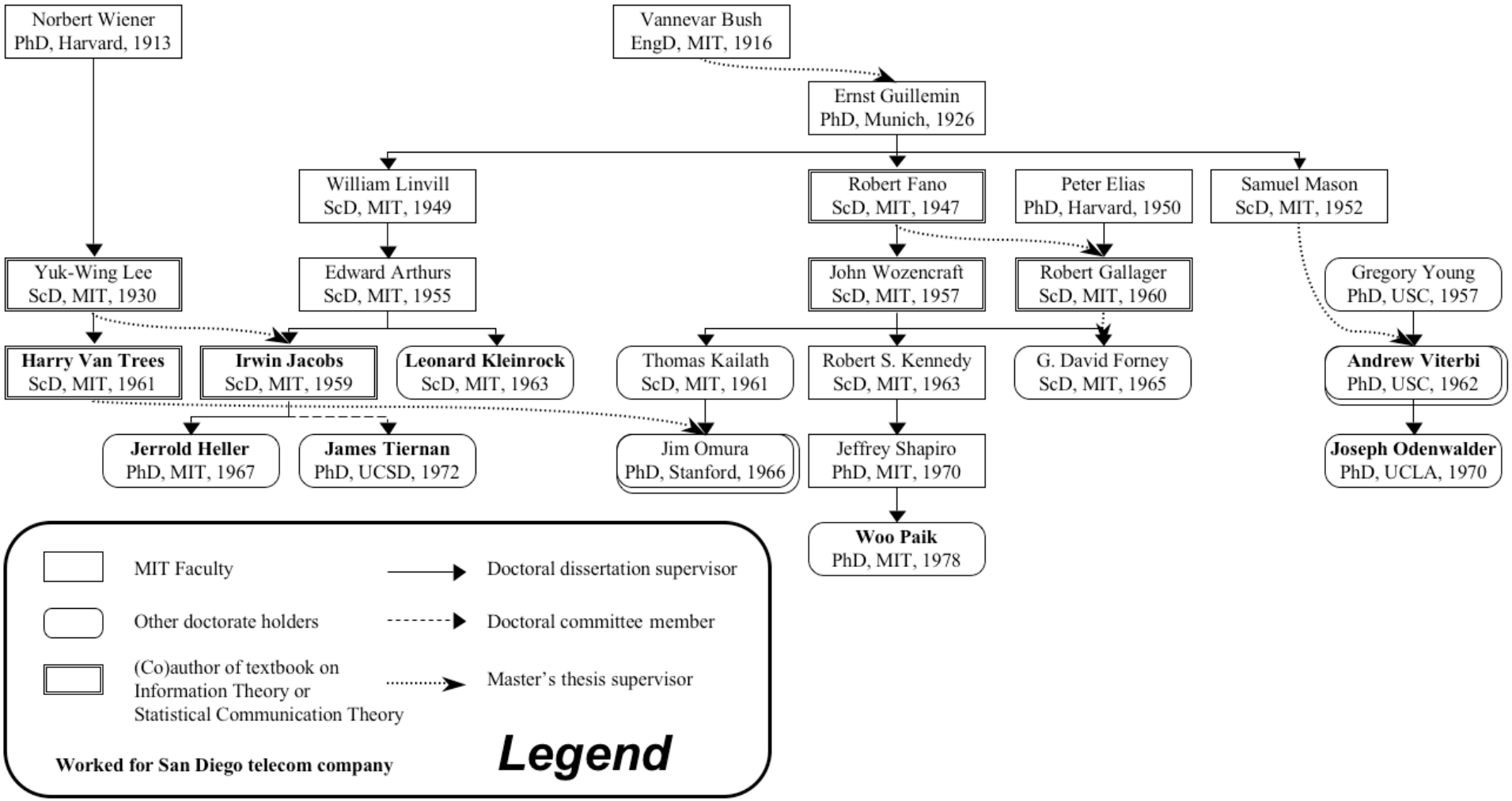
People

- Shannon
- Early Faculty
- Info Theory Grad Students

Shannon @ MIT

- Taught < 10 classes in 22 years
  - 6.575 seems to have a huge impact on people
- Only 2 doctorates and 5 S.M. theses
- Shy, withdraws as health fades
- Best guess as to his role:
  - Limited personal impact
  - But perhaps a draw for prospective students

Academic Genealogy



Early Leaders

- Fano (1947-1962?)
- Elias (1953-)
- Role of Wiener, Lee, Bose, Wiesner?

Info Theory Grad Students

- Those who stay:
  - Wozencraft
  - Gallager
  - Davenport, Jacobs, Van Trees, ?
- Those who leave
  - Huffman, Massey, Berlekamp, Forney
  - Why do they leave?

Ending of the Era

Three possible reasons dominance ends

- Knowledge gets diffused
  - MIT PhDs play major role
- Key researchers fall away
  - Leave MIT
  - Switch to computers: Elias, Fano
- Perception: “Information theory is dead”

Unresolved Questions

Shannon vs. Wiener (Lee)

- Parallel wartime work
  - Wiener (1942) gets first publication
- Shannon is father of information theory
  - Shannon (1948) finishes linkages
  - Shannon (1949) is basis of coding
- Wiener, Lee, Bose mainstay of MIT
  - Is this effect negligible?

MIT Algebraic Coding

- MIT invents, “owns” convolutional codes
- Contributes also to block codes:
  - Huffman coding
  - Reed (Muller) and Reed-Solomon
  - Forney’s concatenated codes
  - Berlekamp’s *Algebraic Coding Theory*
- More competition here
- Most breakthroughs in 1950s

Who Else “Counts”?

- Many info theory researchers at MIT
  - Phone books are boring to read
- Use honors from the field?
  - Shannon Award
  - Other ITSoc awards?
  - IEEE medals prizes?
  - Other awards???
- Other measures?
  - Textbooks, ?

Impact on Industry

- PhDs into industry
  - Forney, Jacobs, Van Trees, Hoversten
- Teaching undergrad/master's students
- Training teachers for elsewhere
  - Stanford
  - Berkeley
  - Notre Dame
  - Brown, Carleton, ?
- How would you measure it?

Discussion

Explaining MIT's Dominance

- One-time paradigm shift?
- Institutions and government funding?
- General student & faculty quality?
  - Reinforced by agglomeration effects?

- Was there a more graceful way to end?

Changing Nature of Comm. Eng.

Shift to science-based engineering:

- Before WW II, communications is a craft
- In WW II, RadLab mixes EE & physics
  - Some evidence physics was essential
- Shannon Theory is all math
  - New probabilistic view
  - In 1950s, most engineers don't get it
  - MIT engineers do

Institutional Factors

- 1940-1960: shift of US university research to government funding
- World War II & Rad Lab are seminal
  - Changes scale of MIT research
  - Changes research culture, attitudes
  - MIT administrations lead US change
- Postwar: unusual pure research $$

General Quality

- MIT is clear leader in engineering & EE
  - Leader in all engineering rankings
  - Leader in EE from 1882-present
- Attracts “best and the brightest”
- No strong competition
  - Harvard, Caltech abdicate role until 1990s
  - Stanford: more entrepreneurial, less science
  - State universities lack resources
  - Success of the polytechnic model

Graceful De-institutionalization?

- MIT pulls back from coding theory
  - “Coding is dead”
  - Huge opportunity in computing & C.S.
- Leaves a huge void that’s never filled
  - Bell Labs plays limited role until it dies
  - UCSD establishes Information Theory and Applications Center in 2006 w/Qualcomm $
- Is there a way to explicitly hand off role?