PUBLIC RELEASE

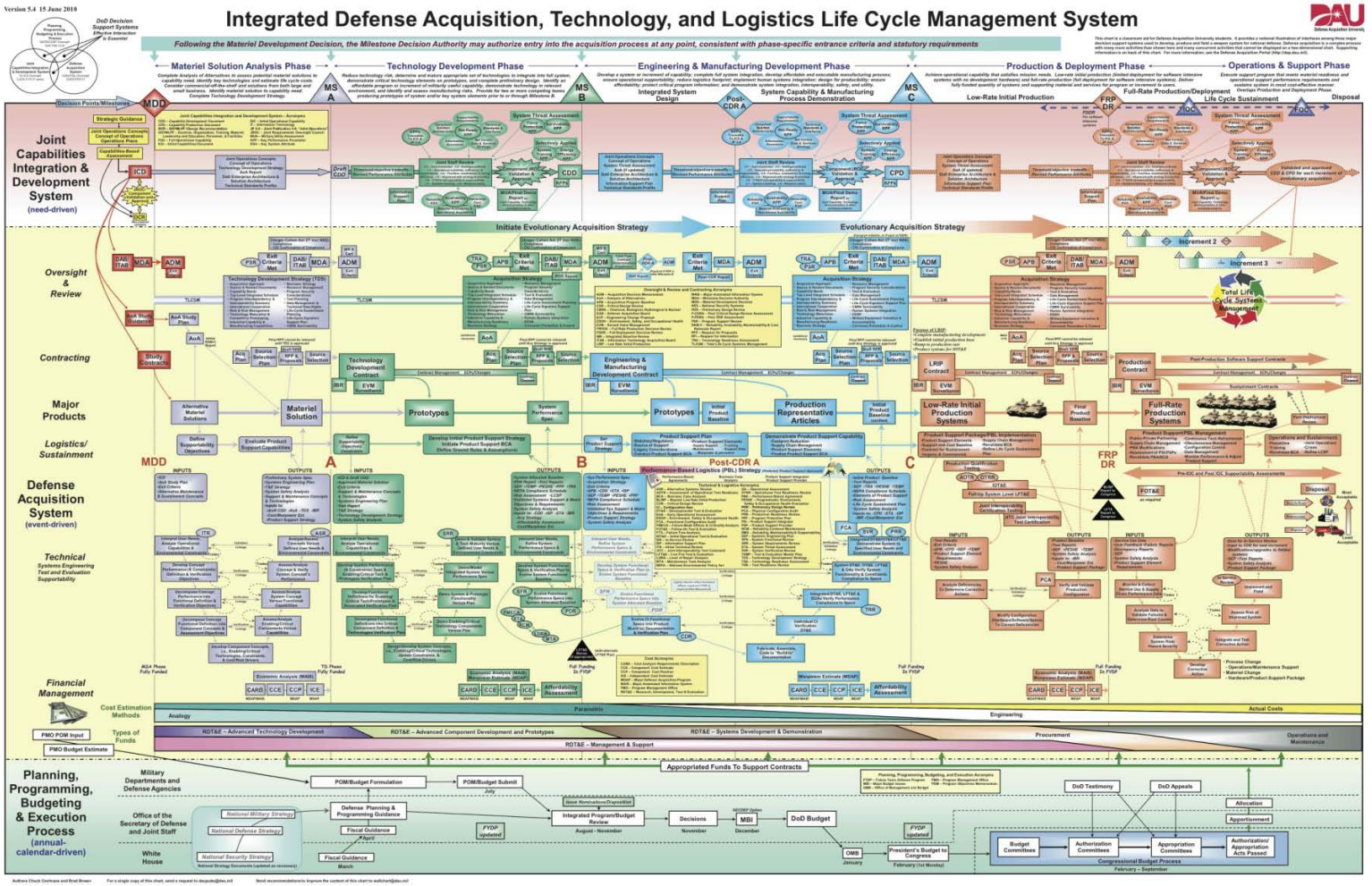
Understanding the Limits of SoS

NDIA Systems Engineering Conference 2010

San Diego, CA
October 27, 2010

Table Of Contents

Motivations

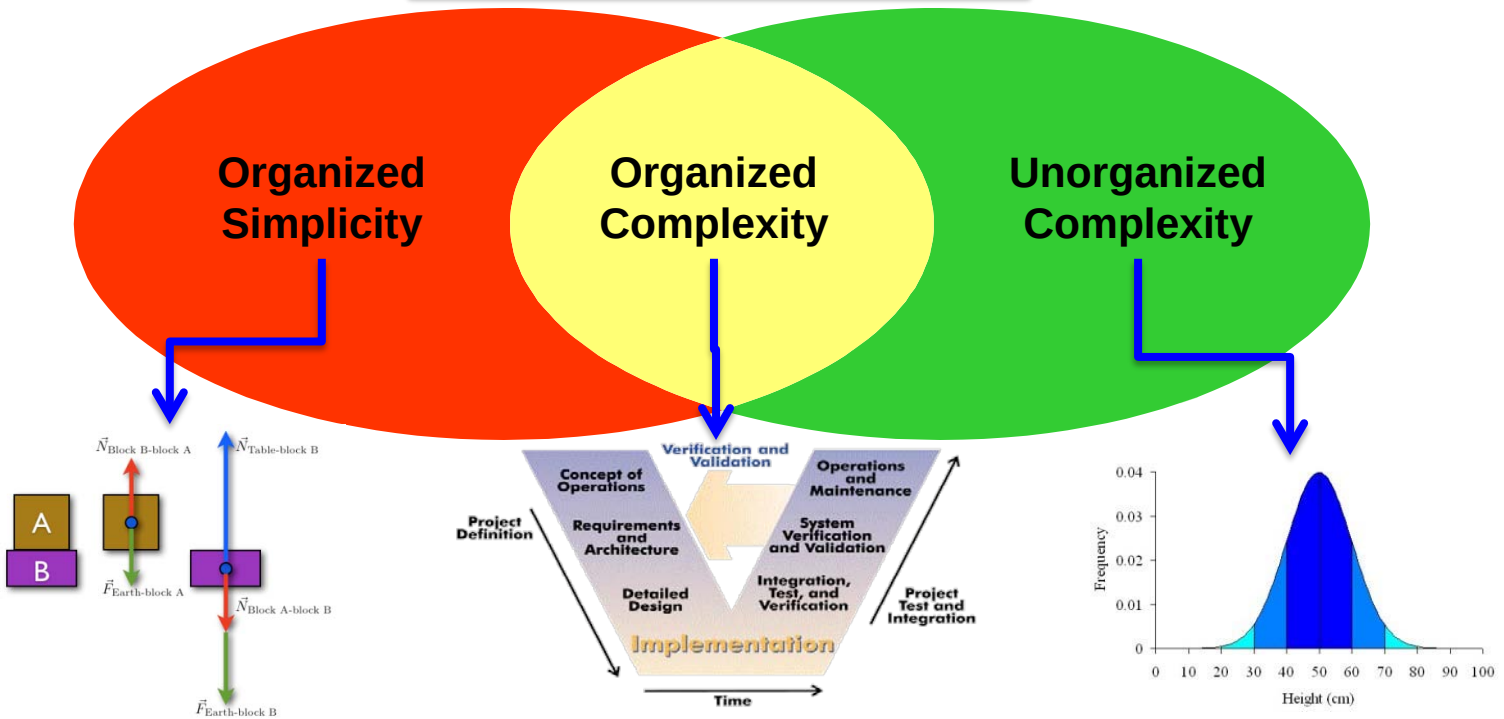


Source: Defense Acquisition University

Our technologies today are complex and highly coupled

- Tight coupling results when components are interdependent
- Complexity results when our tools fail to accurately predict system response

Types of Complexity



Controlled vs. Emergent Systems

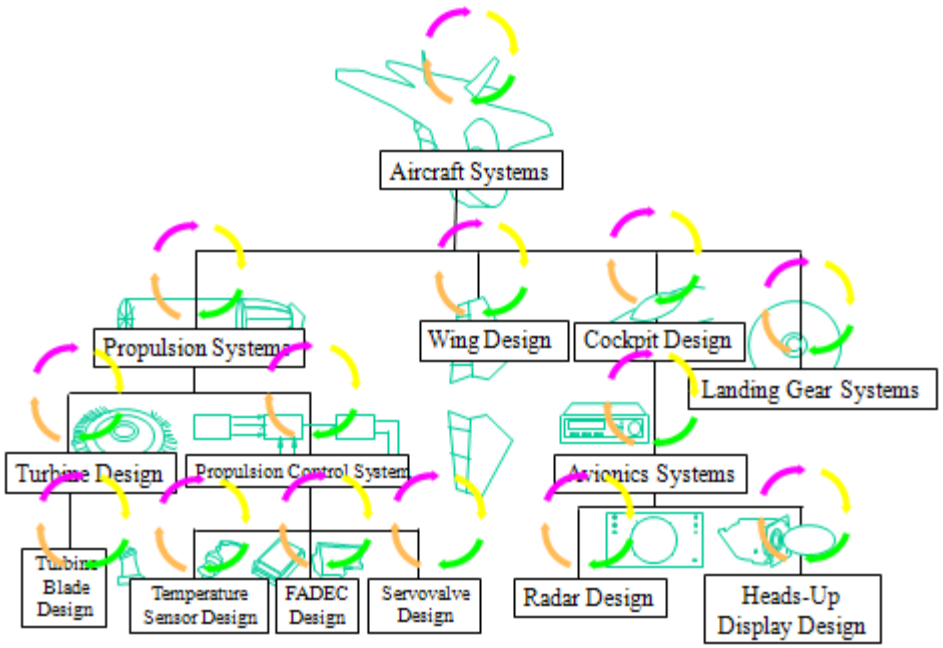
- Controlled systems
  - Militaries
  - Air traffic control
  - Multi-national corporations
  - Software, Hardware
- Emergent systems
  - Intelligence bureaucracy
  - Internet
  - Social networking
  - Biological swarming: Bees, ants, etc.

Background and Previous Research

- George Miller's "Magic Number 7" paper in 1956
  - Ability to differentiate one-dimensional stimuli accurate up to 6 items
  - Short-term memory can keep track of ~ 7 items
- McCabe's Cyclomatic complexity metric
  - Measures number of linearly independent paths through a program (loops)
  - General rule of thumb that software modules should be limited to metric of 10
- DARPA META Complexity Measure

$$C(n, A) = \sum_{i=1}^{n} \alpha_i + \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{4} \beta_k \alpha_{ijk} + \gamma \left[\frac{\log n}{\log 7} \right] E(A)$$

Previous Research



NSF Workshop: Design of Large-Scale Systems, Sept 2010

Item	~ # Parts	# Levels
Screwdriver (B&D)	3	1
Roller Blades (Bauer)	30	2
Inkjet Printer (HP)	300	3
Copier (Xerox)	2000	4
Automobile (GM)	10,000	5
Aircraft (Boeing)	100,000	6+

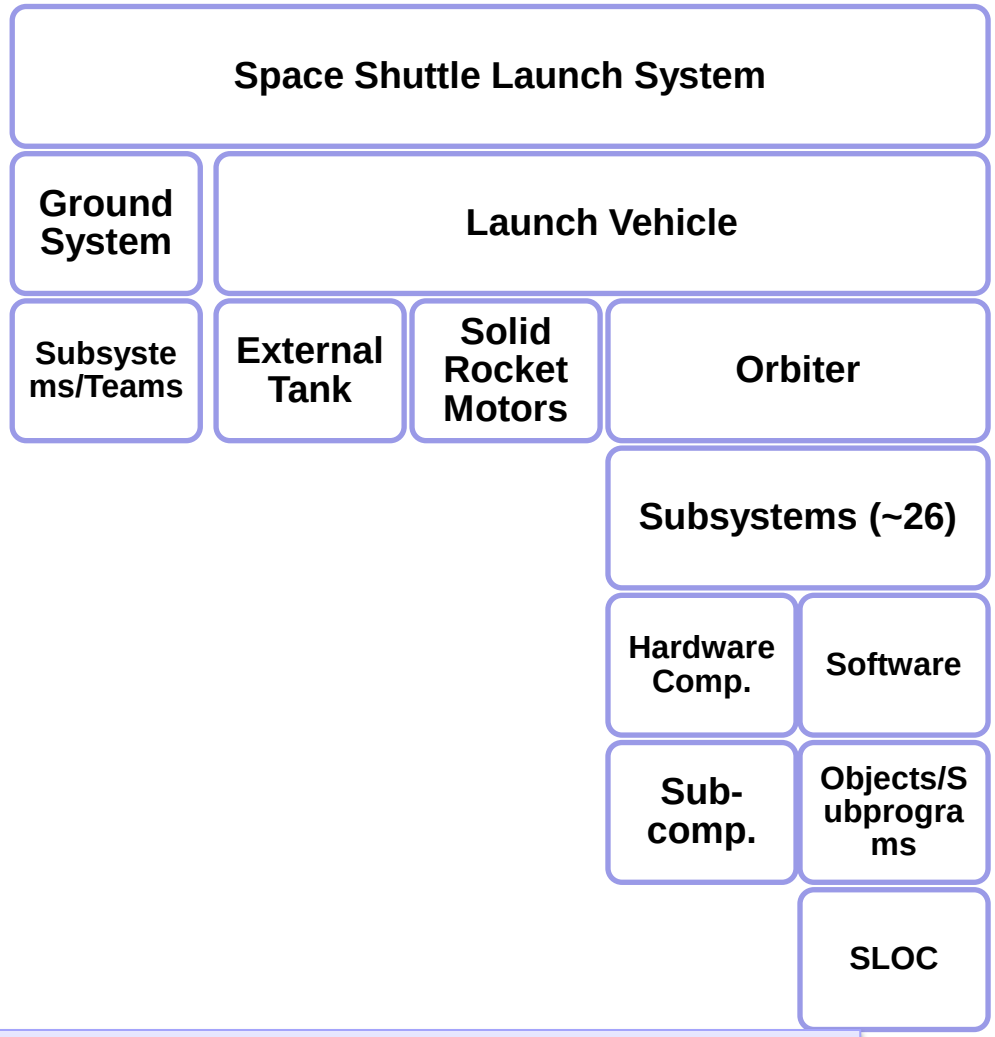
Source: Ulrich, K.T., Eppinger S.D. , Product Design and Development Second Edition, McGraw Hill, 2nd edition, 2000, Exhibit 1-3

Framework

- Survey systems of systems from a broad array of domains
  - Technical
  - Social
  - Biological
  - Political
- Count abstraction levels
- Count heterogeneous elements at each abstraction level
  - Functional
  - Attributes

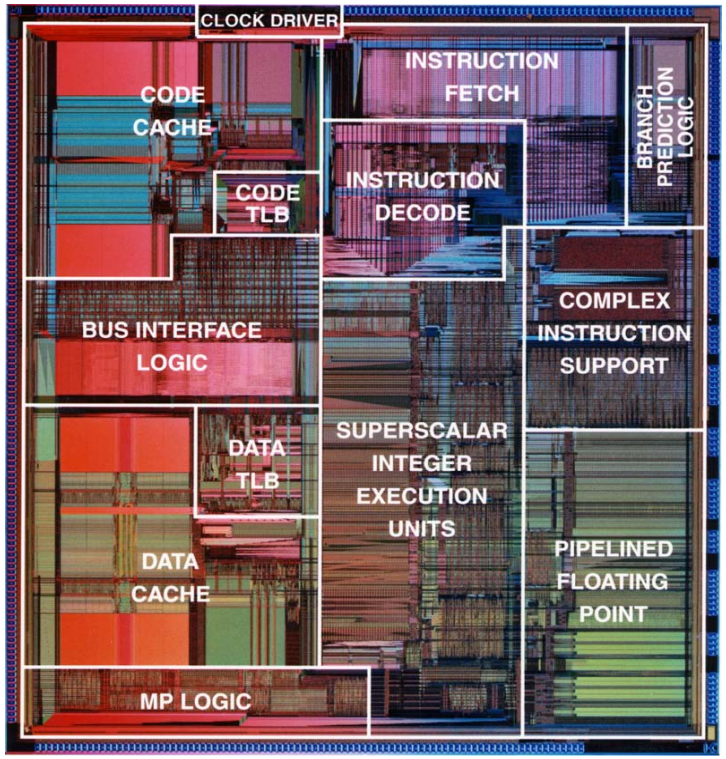
Launch System

Source: NASA



7 Levels – 2.5M parts, 2M SLOC

Microprocessor



Source: Intel Pentium Processor

Microprocessor

Components (ALU, FPU, Registers, etc.) (15 – 20)

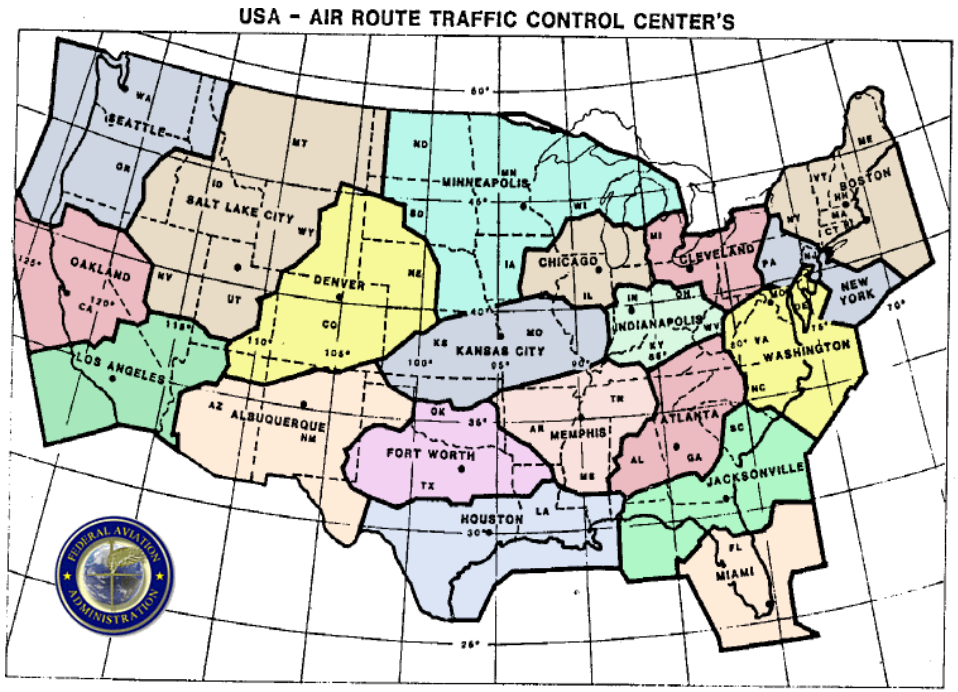
Logic Functions (NOR, AND, MUX, etc) (~20 types)

Transistors (2-30 per Logic Function, 2.3 Billion in 8-core Xeon Processor)

Substrates

5 Levels – 2.3B transistors

Air Traffic Control



Source: FAA

National Air-Traffic Control

Area Control Center (20 Centers)

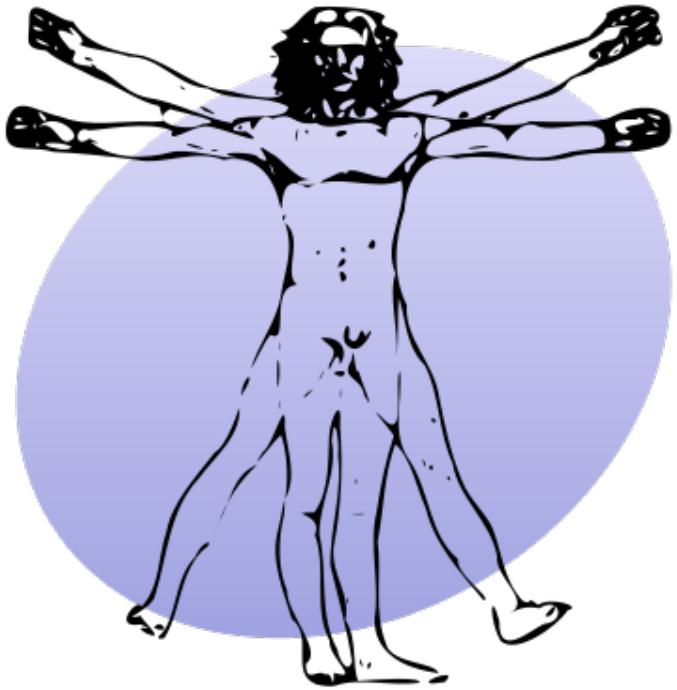
TRACON (Terminal Radar Approach Control Center) (830)

Airport Traffic Control (5200 Airports)

Air Control	Ground Control	Flight Data/Clearance Delivery	Apron Control	Ground Movement Control

5 Levels – 55,000 flights per day

Biological Systems



Source: Wikipedia

Human Body

Systems (11)

Organs (78)

Tissue (4)

Cells (10 trillion)

5 Levels – 10T cells

WAL★MART

Source: Wikipedia

- Walmart (Board of Directors)
- CEO
- Officers
- Regional VPs (41)
- Districts (~11/Region)
- Stores (~6 to 8/District)
- Assistant Manager
- Department Manager (~40)
- Cashier
- Sales Associates
- Stocker

8 Levels – ~2M employees, 8500 Stores

Department of Defense

Secretary of Defense

Deputy Secretary of Defense

Office of the Inspector General of the Department of Defense

Office of the Secretary of Defense

Under Secretaries of Defense, Assistant Secretaries of Defense, and other specified officials

Department of the Army

Secretary of the Army

- Office of the Secretary of the Army
- The Army Staff
  - The Army

Department of the Navy

Secretary of the Navy

- Office of the Chief of Naval Operations
  - The Navy
- Office of the Secretary of the Navy
- Headquarters Marine Corps
  - The Marine Corps

Department of the Air Force

Secretary of the Air Force

- Office of the Secretary of the Air Force
- The Air Staff
  - The Air Force

The Organization of the Joint Chiefs of Staff

Chairman of the Joint Chiefs of Staff

- The Joint Staff

The Defense Agencies

- Defense Advanced Research Projects Agency
- Defense Business Transformation Agency
- Defense Commissary Agency
- Defense Contract Audit Agency
- Defense Contract Management Agency
- Defense Finance and Accounting Service
- Defense Information Systems Agency
- Defense Intelligence Agency
- Defense Legal Services Agency
- Defense Logistics Agency
- Defense Security Cooperation Agency
- Defense Security Service
- Defense Threat Reduction Agency
- Missile Defense Agency
- National Geospatial-Intelligence Agency
- National Reconnaissance Office
- National Security Agency/Central Security Service
- Pentagon Force Protection Agency

DoD Field Activities

- Defense Media Activity
- Defense Prisoner of War/Missing Personnel Office
- Defense Technical Information Center
- Defense Technology Security Administration
- DoD Education Activity
- DoD Human Resources Activity
- DoD Test Resource Management Center
- Office of Economic Adjustment
- TRICARE Management Activity
- Washington Headquarters Services

Combatant Commands

- US Africa Command
- US Central Command
- US European Command
- US Joint Forces Command
- US Northern Command
- US Pacific Command
- US Southern Command
- US Special Operations Command
- US Strategic Command
- US Transportation Command

Prepared by: Directorate for Organizational and Management Planning/Office of the Director, Administration and Management/Office of the Secretary of Defense May 2010

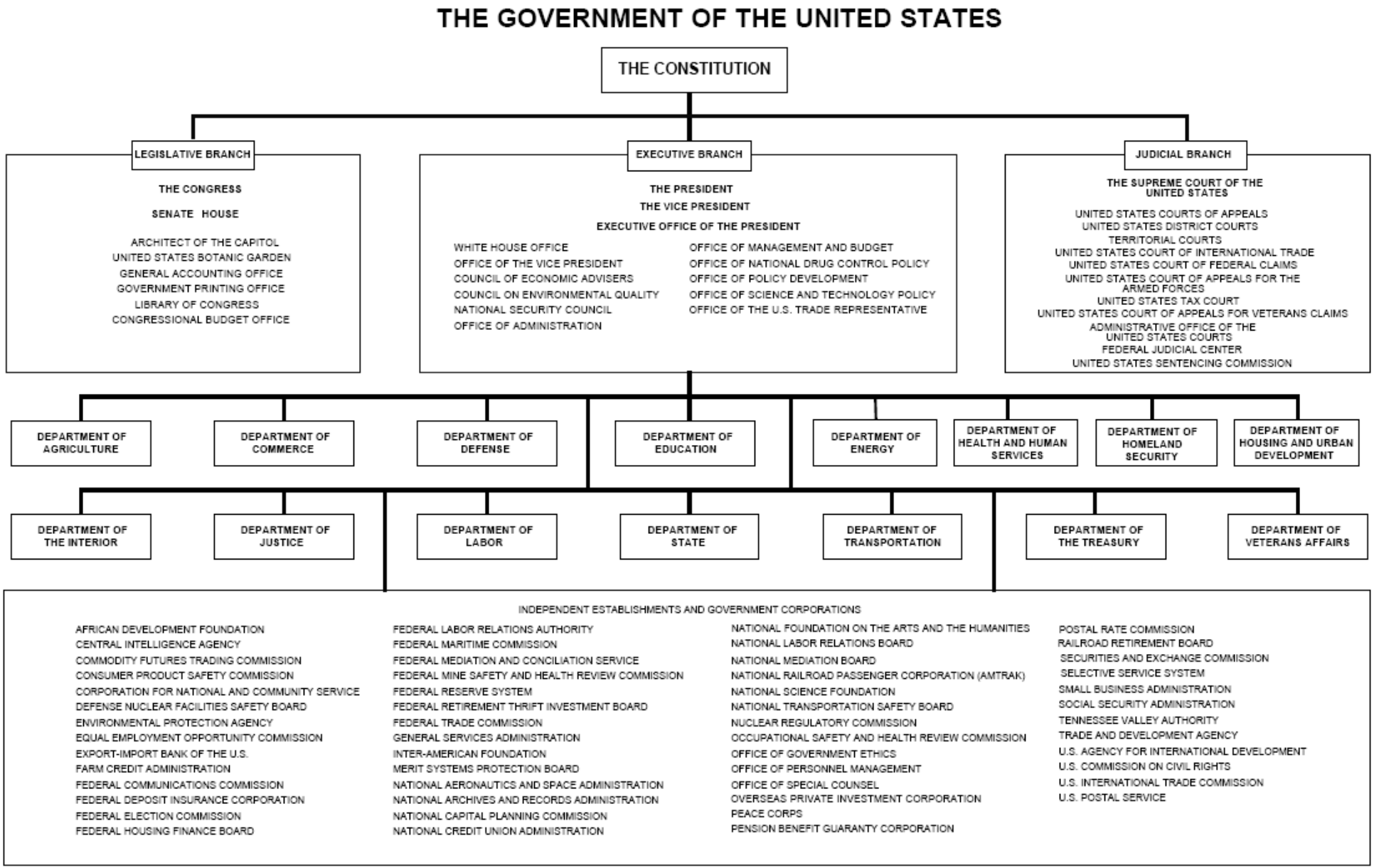
3+ Levels, 2.1M Personnel

US Air Force

Source: Wikipedia

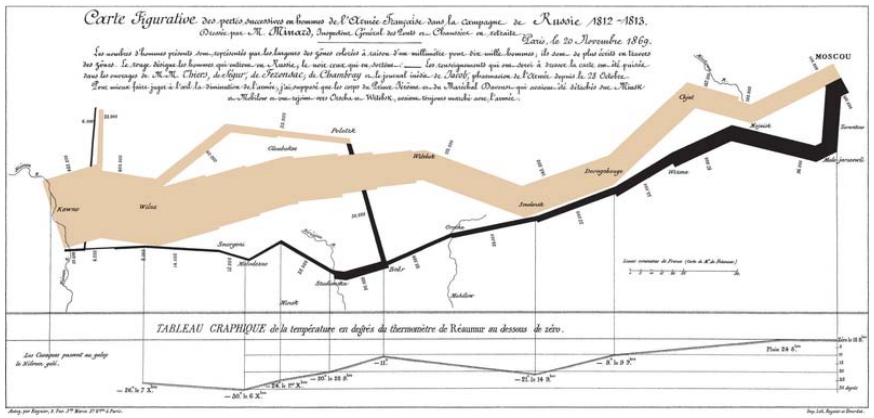
- **Air Force Headquarters**
- **Major Command (10)**
- **Numbered Air Force (24)**
- **Wing (243)**
- **Group**
- **Squadron (300)**
- **Flight**
- **Airman**

7 - 8 Levels – 330,000 personnel



3 Levels (+ x Levels) – 21M personnel

The Grande Armée



Napoleon			
Imperial Guard	**Corps (5-7)**		
	Artillery Brigade	**Infantry Division (4k – 10k per Corp)**	**Calvary Division (2k to 4k per Corp)**
		Brigade (2-3 per Corp)	**Brigade (2-3 per Corp)**
		Regiment (2 per Brigade)	**Regiment (2 per Brigade)**
		Infantryman (~10 per Regiment)	**Cavalryman**

6 Levels – 600,000 soldiers

Summary

- Miller's Magic Number 7 leads to maximum of ~960,000 parts
  - No clear limits
- Further research needed:
  - More surveys in a variety of systems
  - Interactions between Systems of Systems (i.e. Technical vs. Social)
- Emergent systems as opposed to controlled systems?