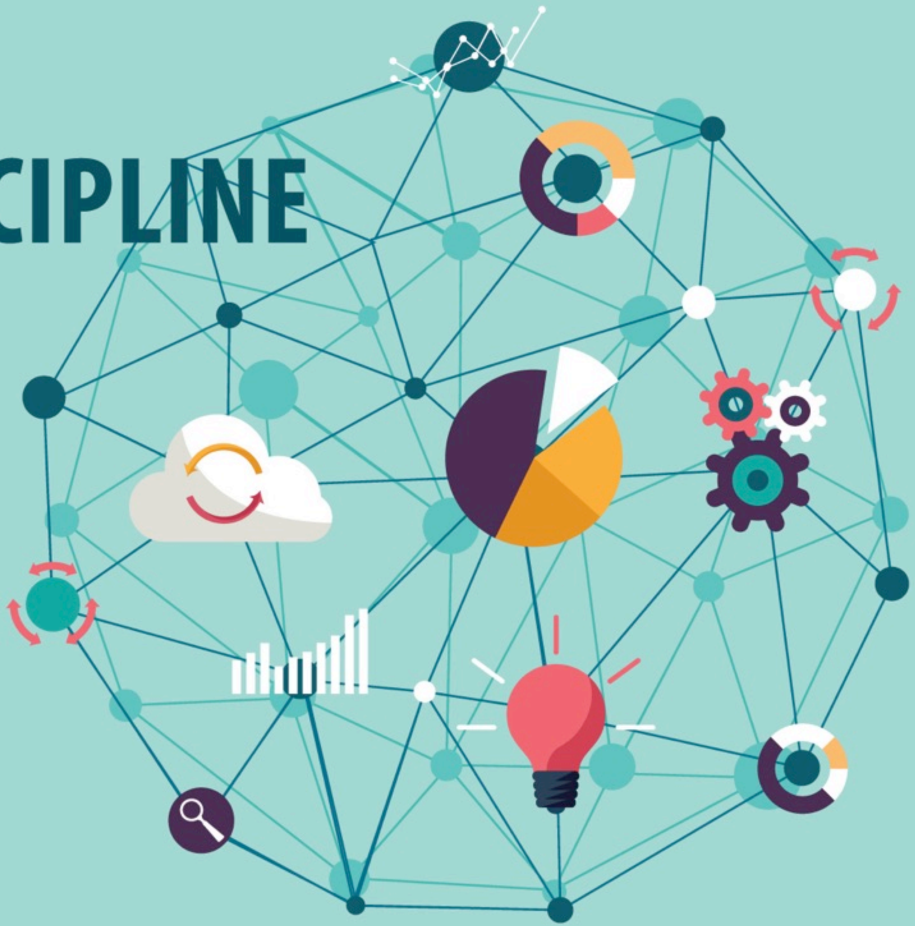
Envisioning the

DATA SCIENCE DISCIPLINE

The Undergraduate Perspective



Webinar Series
Fall 2017

The National Academies of SCIENCES ENGINEERING MEDICINE

nas.edu/EnvisioningDS

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9/12/17 – Building Data Acumen *(recording posted)*

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10/17/17 – Ethics

10/24/17 – Assessment and Evaluation for Data Science Programs

11/7/17 – Diversity, Inclusion, and Increasing Participation

11/14/17 – Two-Year Colleges and Institutional Partnerships

Provide input, download the interim report, and learn more about the study at www.nas.edu/EnvisioningDS

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Inter-Departmental Collaboration & Institutional Organization

Mark Embree, Virginia Tech

Professor, Department of Mathematics
Leader, Computational Modeling and Data Analytics (CMDA) division
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Liew Family Chair of Computer Science
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Forging Virginia Tech's CMDA Major Across Departments

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Virginia Tech's CMDA Major

CMDA = Computational Modeling and Data Analytics

The CMDA undergraduate major was founded in 2015 as a collaboration between CS, Math, and Statistics, via the leadership of Dean of Science Lay Nam Chang.

In addition to existing faculty who shaped the program, VT has hired

- Five tenure track faculty in Math (including two full professors);
- Two tenure track faculty and one collegiate faculty in Statistics.

This year (2017–2018), CMDA will hire four faculty:

- Tenure track in Math
- Tenure track and collegiate faculty in Statistics
- Tenure track in Economics

VirginiaTech

Ingredients of CMDA Curriculum

STATISTICS FOR BIG DATA

Data mining, machine learning, visualization

APPLIED MATHEMATICS FOR MODELING

Linear algebra, differential equations, numerical analysis

HIGH-PERFORMANCE COMPUTING

Parallel/GPU programming for data/science/engineering apps

ACCESS TO RELEVANT APPLICATIONS

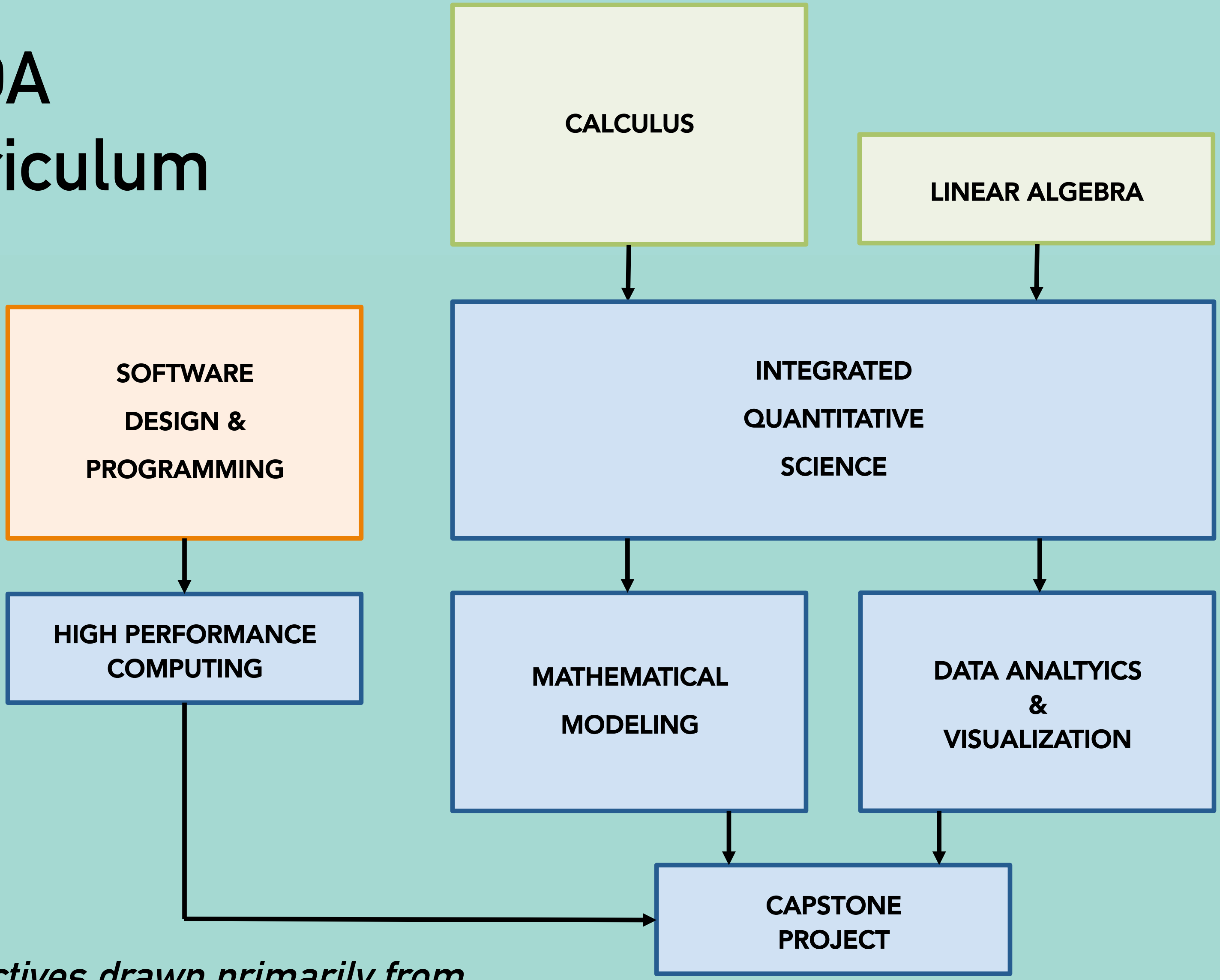
Natural and social sciences, engineering, humanities, internet

Specialized degree options in Economics, Physics, more coming.

PRACTICAL SKILLS FOR PROBLEM SOLVING (CAPSTONE)

Ethics, collaboration, leadership, presentation skills

CMDA Curriculum



CALCULUS

LINEAR ALGEBRA

SOFTWARE DESIGN & PROGRAMMING

INTEGRATED QUANTITATIVE SCIENCE

HIGH PERFORMANCE COMPUTING

MATHEMATICAL MODELING

DATA ANALTYICS & VISUALIZATION

CAPSTONE PROJECT

Four electives drawn primarily from

CMDA

COMPUTER SCIENCE

MATHEMATICS

STATISTICS

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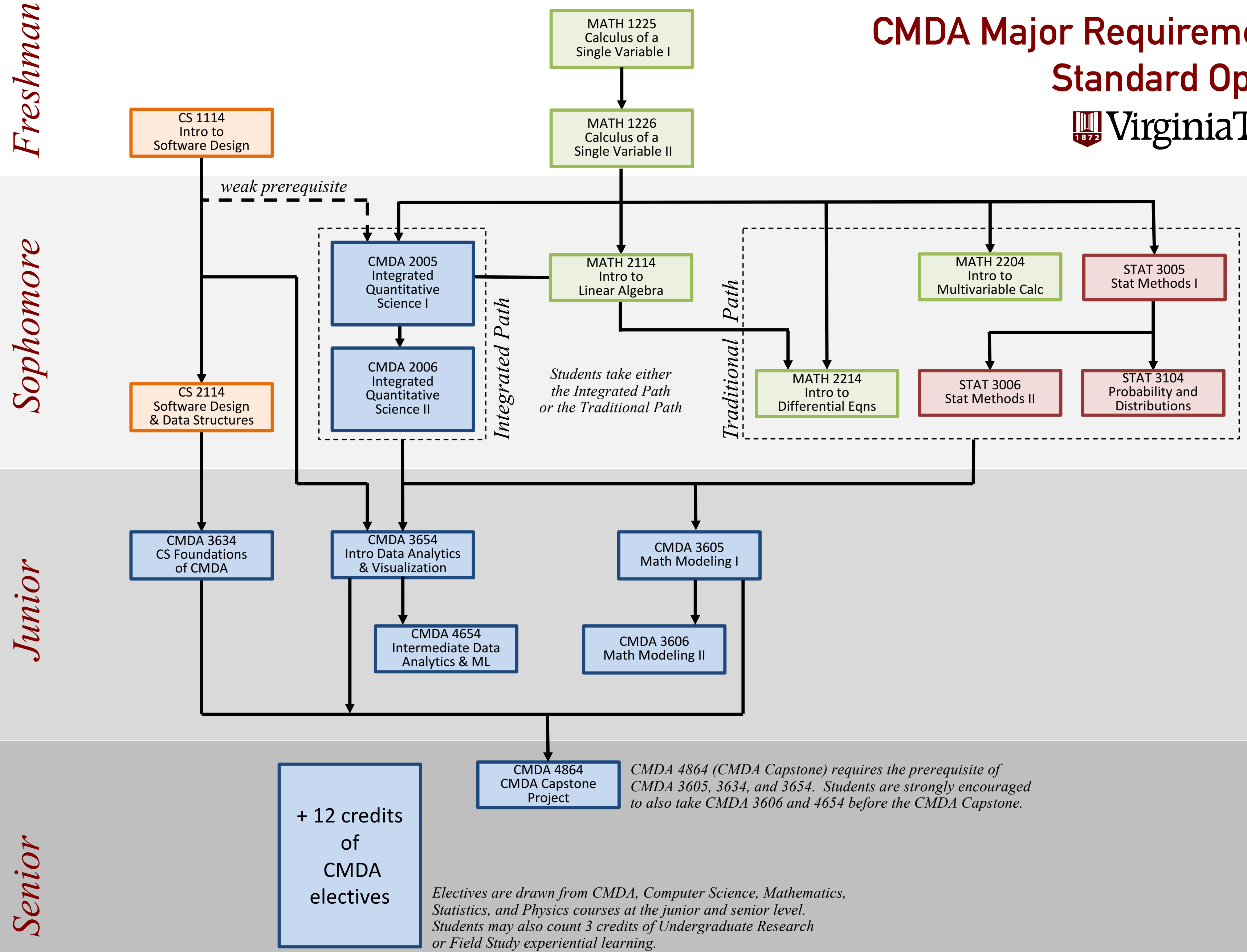
CMDA Major Requirements
Standard Option

VirginiaTech



Freshman

MATH 1225
Calculus of a
Single Variable I

MATH 1226
Calculus of a
Single Variable II

CS 1114
Intro to
Software Design

Sophomore

weak prerequisite

Integrated Path

CMDA 2005
Integrated
Quantitative
Science I

CMDA 2006
Integrated
Quantitative
Science II

MATH 2114
Intro to
Linear Algebra

*Students take either
the Integrated Path
or the Traditional Path*

Traditional Path

MATH 2204
Intro to
Multivariable Calc

STAT 3005
Stat Methods I

MATH 2214
Intro to
Differential Eqns

STAT 3006
Stat Methods II

STAT 3104
Probability and
Distributions

CS 2114
Software Design
& Data Structures

Junior

CMDA 3634
CS Foundations
of CMDA

CMDA 3654
Intro Data Analytics
& Visualization

CMDA 3605
Math Modeling I

CMDA 4654
Intermediate Data
Analytics & ML

CMDA 3606
Math Modeling II

Senior

CMDA 4864
CMDA Capstone
Project

CMDA 4864 (CMDA Capstone) requires the prerequisite of CMDA 3605, 3634, and 3654. Students are strongly encouraged to also take CMDA 3606 and 4654 before the CMDA Capstone.

+ 12 credits
of
CMDA
electives

Electives are drawn from CMDA, Computer Science, Mathematics, Statistics, and Physics courses at the junior and senior level. Students may also count 3 credits of Undergraduate Research or Field Study experiential learning.

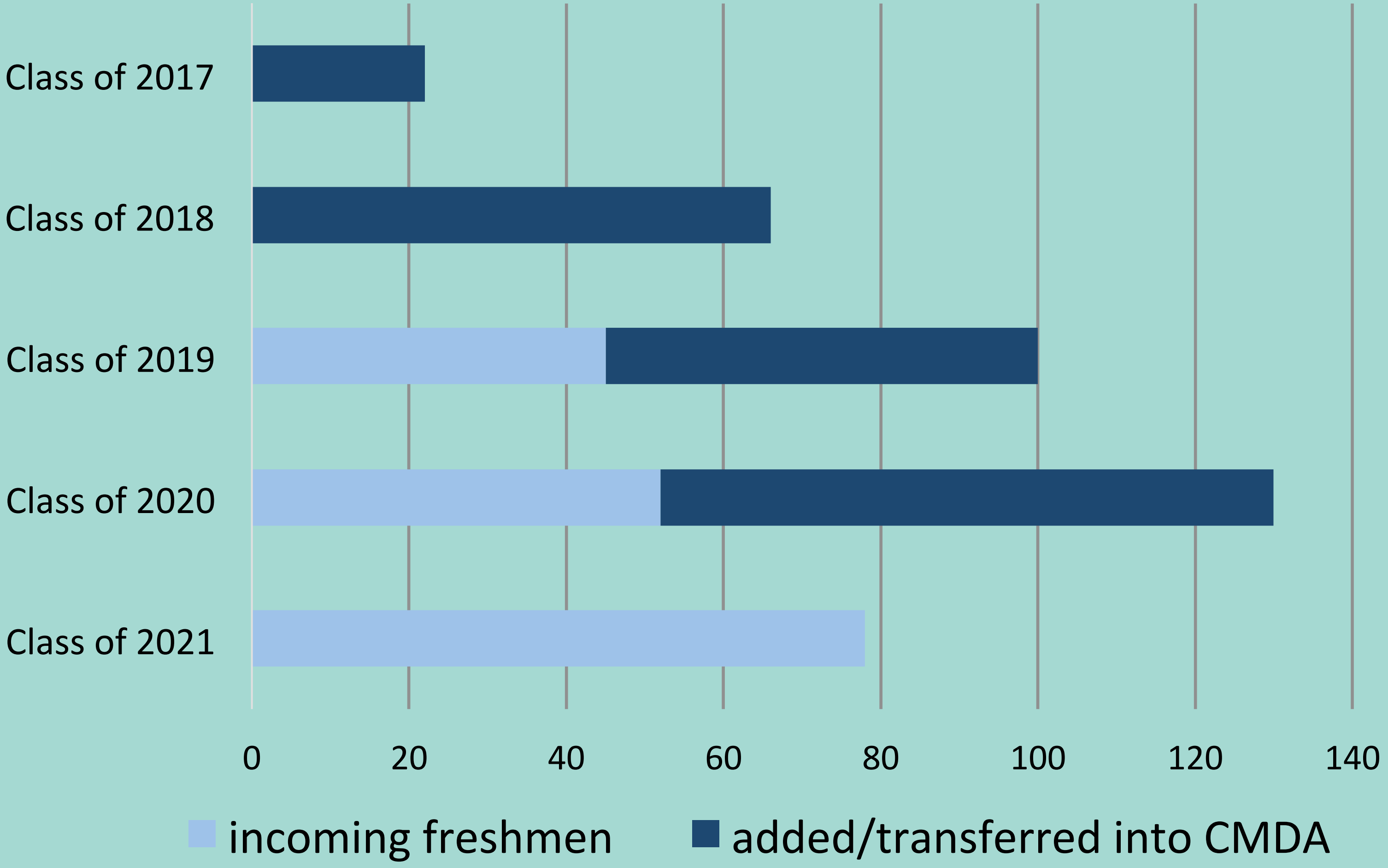
CMDA History

Planning for the CMDA major began around 2012, a collaboration of a dozen faculty in Computer Science, Mathematics, Physics, and Statistics.

The curriculum builds on faculty research interests in applied math, high performance scientific computing and Bayesian analytics.

2013	*CMDA proposal finalized*
SPRING 2014	*CMDA approved by Virginia Tech's Board of Visitors*
JULY 2014	*CMDA approved by State Council on Higher Ed. (SCHEV)*
SPRING 2015	*Students can first declare the CMDA major*
FALL 2015	*First freshman class arrives (45 students)*
FALL 2016	*Second freshman class arrives (52 students)*
MAY 2017	*First graduation (22 students)*

CMDA Enrollment



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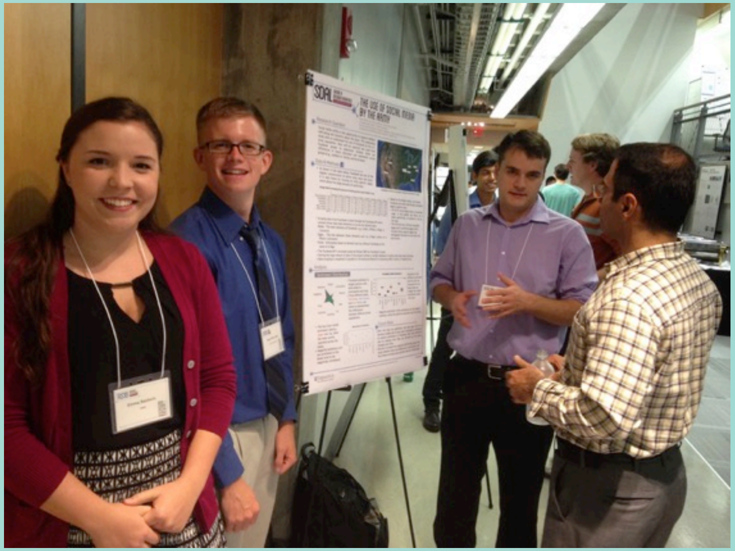
Capstone Project Course

- Teams of 3–4 students work on one project for the entire semester.
- Projects come from external clients (companies or within VT).
- Teams are guided through a methodical problem-solving process.
- Focus on teamwork, leadership, collaboration skills, ethics, project management, and communications (written, visual, oral).



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Capstone Projects for Fall 2017

Project sponsors from Virginia Tech:

- **Math Emporium** (tutor response speed; quiz analytics)
- **Economics Department** (infrastructure failures)
- **Social and Decision Analytics Lab** (open source software)
- **Biocomplexity Institute** (sick tweeting; disease dynamics)
- **VT Center for Autism Research** (geographic disparities)
- **VT Athletics Department** (press release effectiveness)

Industry Capstone Sponsors
Fall 2017

Akamai
SOCIALLYDETERMINED
Anthem.
MITRE
OZMO
VERACITY
FORECASTING AND ANALYSIS
Booz | Allen | Hamilton
GENERAL DYNAMICS
Mission Systems
JENSEN HUGHES
GE Aviation
OCTO

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Reflections on CMDA Curriculum

MATH MATTERS

The foundational math curriculum is demanding compared to some data science programs, but the foundation unlocks the ability to dig deeply into modern algorithms.

DATA SCRAPING IS AN EMPOWERING TECHNOLOGY

Once students learn to scrape data, they are empowered to pursue their own favorite applications as side projects.

HIGH PERFORMANCE COMPUTING FOR THE MASSES

Many CMDA majors arrive with little programming experience, but they all end up learning (and usually enjoying) HPC.

A MISSING INGREDIENT: HIGH PERFORMANCE DATABASES

We would like to add a course in high performance data (as well as conventional databases); cf. [De Veaux et al. 2017].

Administrative Structure

CMDA is administratively housed in the College of Science, though the key departments span two colleges:

- Computer Science (College of Engineering)
- Mathematics (College of Science)
- Statistics (College of Science)

Current CMDA degree options engage with

- Economics (College of Science)
- Physics (College of Science)

but could easily expand into departments in other colleges.

Administrative Structure

The College of Science set up the ***Academy of Integrated Science (AIS)***, a department-level unit that administers the College's interdisciplinary programs:

- B.S. CMDA
- B.S. Nanoscience
- B.S. Systems Biology
- Minor in Science, Technology, and Law
- Integrated Science Curriculum (freshmen/sophomores)

The AIS manages budgets, undergrad advising, student recruiting, and assessment for CMDA.

The CMDA faculty director reports to the AIS director,
Prof. Michel Pleimling (Physics).

CMDA Faculty Expectations

Faculty are hired into a home department (e.g. Math, Stats), governed by a Memorandum of Understanding with AIS.

- Each CMDA hire obliges the home department to teach two CMDA classes per year.
- These courses need not be taught by the CMDA faculty member (though they usually are).
- CMDA hires devote much of their service to CMDA, rather than their departments.
- The AIS and CMDA directors contribute a letter to tenure/ promotion dossiers for CMDA faculty.

1872 VirginiaTech

Challenge 1: Hiring

How can we best hire into an interdisciplinary program?
We have learned a few lessons over the past few years.

- ***The home department should lead the search.***
  Candidates need to understand clearly that the tenure home is in the department, not the AIS. The search should look like a departmental search, but with CMDA faculty on the hiring committee, and a meeting with the AIS director.
- ***The candidate's role in CMDA must be clearly articulated.***
  The role must be clear and understood by all interviews.
- ***The interdisciplinary program should be an attractor.***
  Rather than teaching conventional courses, candidate can teach more innovative curriculum that aligns well with research interests.
- ***Reinforce these messages with current CMDA faculty.***
- ***Introduce the candidate to CMDA students.***

Challenge 2: Teaching

CMDA teaching needs good collaboration with departments.

- During our boot-up, CMDA teaching needs outstrip departmental teaching obligation from CMDA hires.
- *Innovative new courses need creative teachers* – often strong faculty who are popular with students.
- Fast growing program demands extra sections beyond initial projections: flexibility is needed.
- GTA resources come from departments (CMDA does not have a graduate degree).
- Good communication between CMDA leader and department chairs is key!

Challenge 3: Number of Majors

CMDA attracts students to VT (often from out of state).
More students transfer into CMDA once they are at VT.

Number of CMDA majors:

- Smaller than CS
- Comparable to Math
- Much larger than Statistics

CMDA draws students away from CS and Math.

- Pro: CMDA is a better fit for some students
- Con: could spark rivalry with departments, depending on how university budget is allocated.

Summary

- Faculty are excited about this interdisciplinary project.
- Students are responding; so are employers.
- Deans of Science (Lay Nam Chang and Sally Morton) have been vital boosters for CMDA.
- Generous department chairs are essential:
  - Cal Ribbens (Computer Science)
  - Peter Haskell (Mathematics)
  - Eric Smith and Ron Fricker (Statistics)
- Good communication is vital.

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Q&A

embree@vt.edu

VirginiaTech

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Some Thoughts on Data Science Education for Undergraduates

Michael Franklin, University of Chicago

Liew Family Chair of Computer Science

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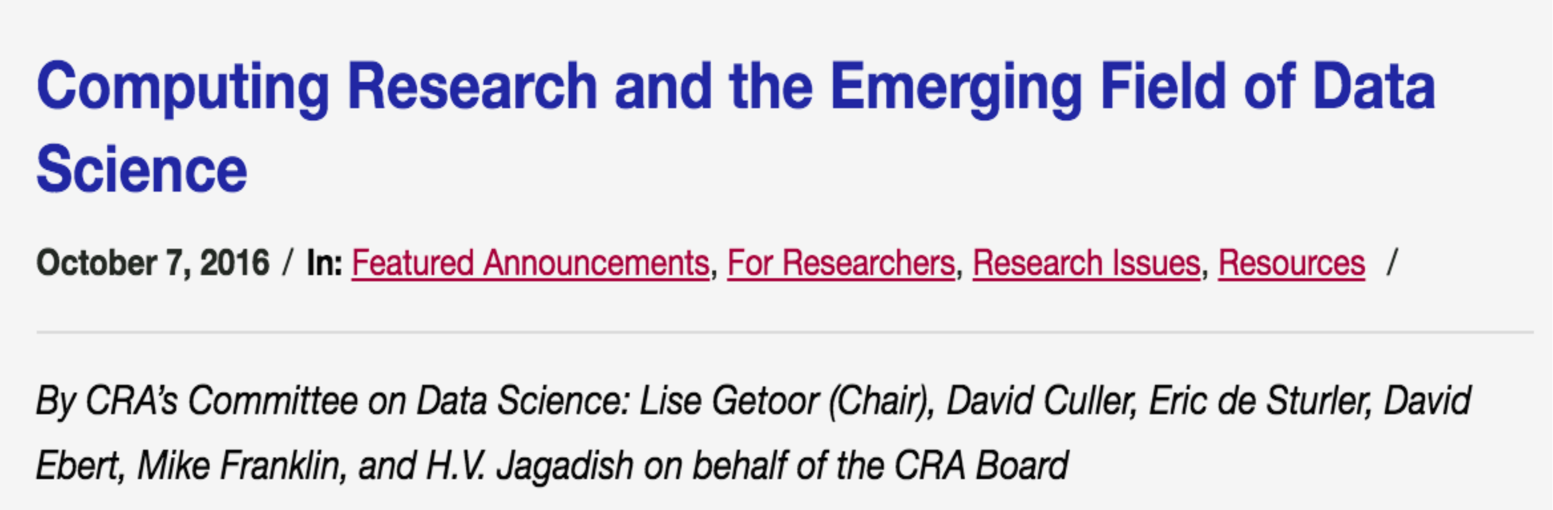


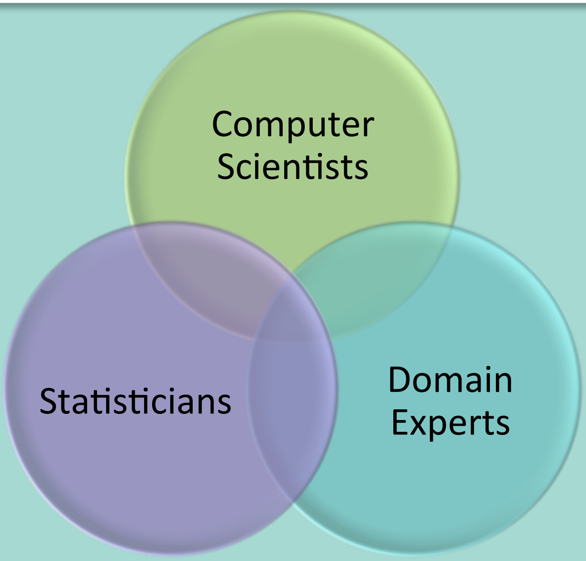
Computing Research and the Emerging Field of Data Science

October 7, 2016 / In: Featured Announcements, For Researchers, Research Issues, Resources /

By CRA's Committee on Data Science: Lise Getoor (Chair), David Culler, Eric de Sturler, David Ebert, Mike Franklin, and H.V. Jagadish on behalf of the CRA Board

CRA

Computing Research Association



"… data science provides new opportunities for creative collaborations between industry, academia and government for pure and applied research."

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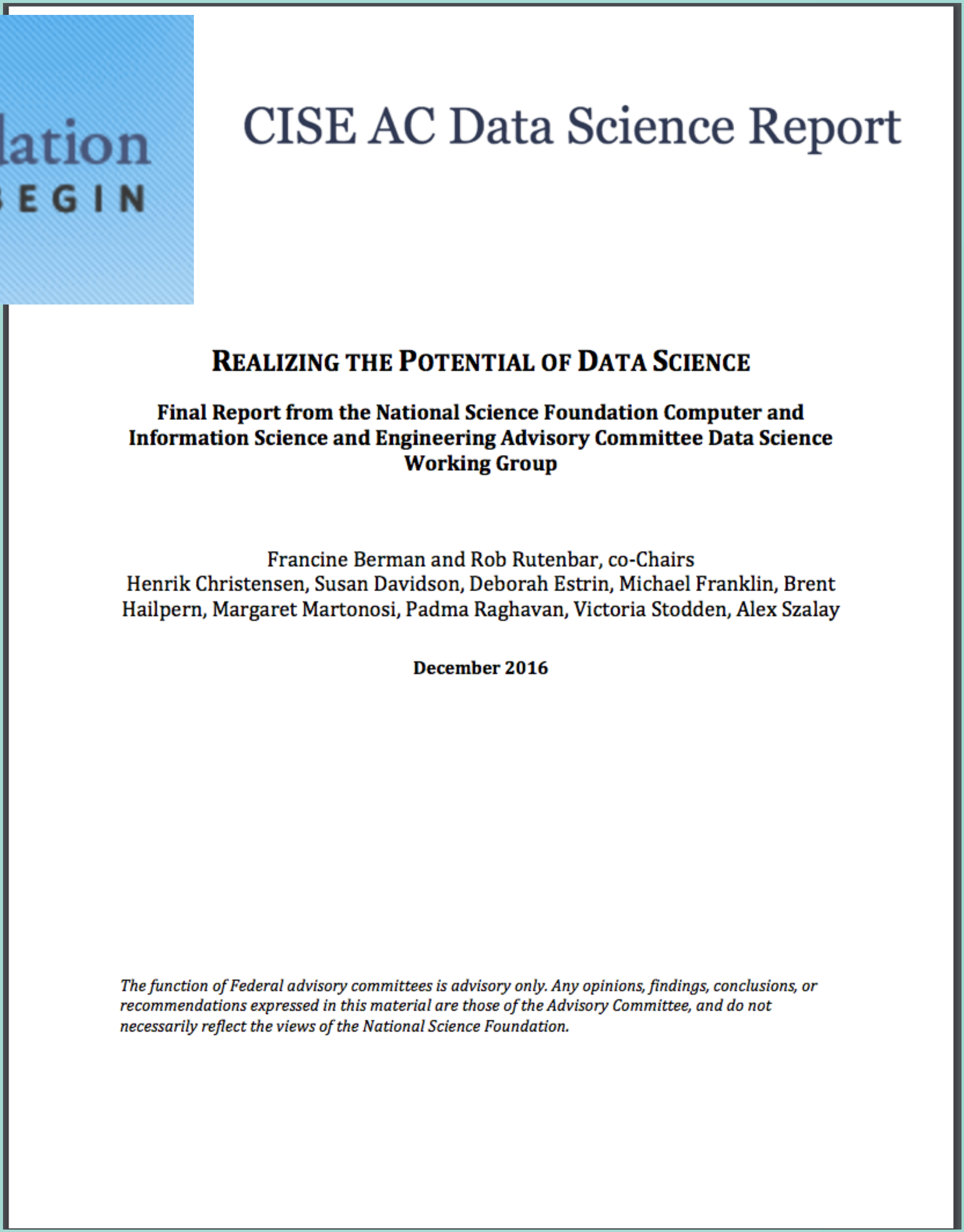
National Science Foundation
WHERE DISCOVERIES BEGIN

If NSF can help foster the evolution and development of both Data Science and Data Scientists over the next decade, we can begin to meet the potential of Data Science to drive new discovery and innovation…

This should include not only a focus on fundamental Data Science, but also on **translational efforts** to move ideas from research to practice across the broadest landscape of commercial applications.

CISE AC Data Science Report



REALIZING THE POTENTIAL OF DATA SCIENCE

Final Report from the National Science Foundation Computer and Information Science and Engineering Advisory Committee Data Science Working Group

Francine Berman and Rob Rutenbar, co-Chairs
Henrik Christensen, Susan Davidson, Deborah Estrin, Michael Franklin, Brent Hailpern, Margaret Martonosi, Padma Raghavan, Victoria Stodden, Alex Szalay

December 2016

The function of Federal advisory committees is advisory only. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the Advisory Committee, and do not necessarily reflect the views of the National Science Foundation.

Provide input and learn more about the study at www.nas.edu/EnvisioningDS

Data Science Programs at U Chicago

MS in Computational Analysis and Public Policy (CAPP)

- Yr 1: Stats, Econ, CS w/apps, DB, ML for Policy
- Yr 2: Analytical Politics, Program Eval, Capstone…

MA in Computational Social Science

- Yr 1: CS w/apps; Perspectives on Analysis, Modeling, Computing; Math & Stats
- Yr 2: Computational Methods, Social Sci, Capstone

Joint **MBA/MS in CS**

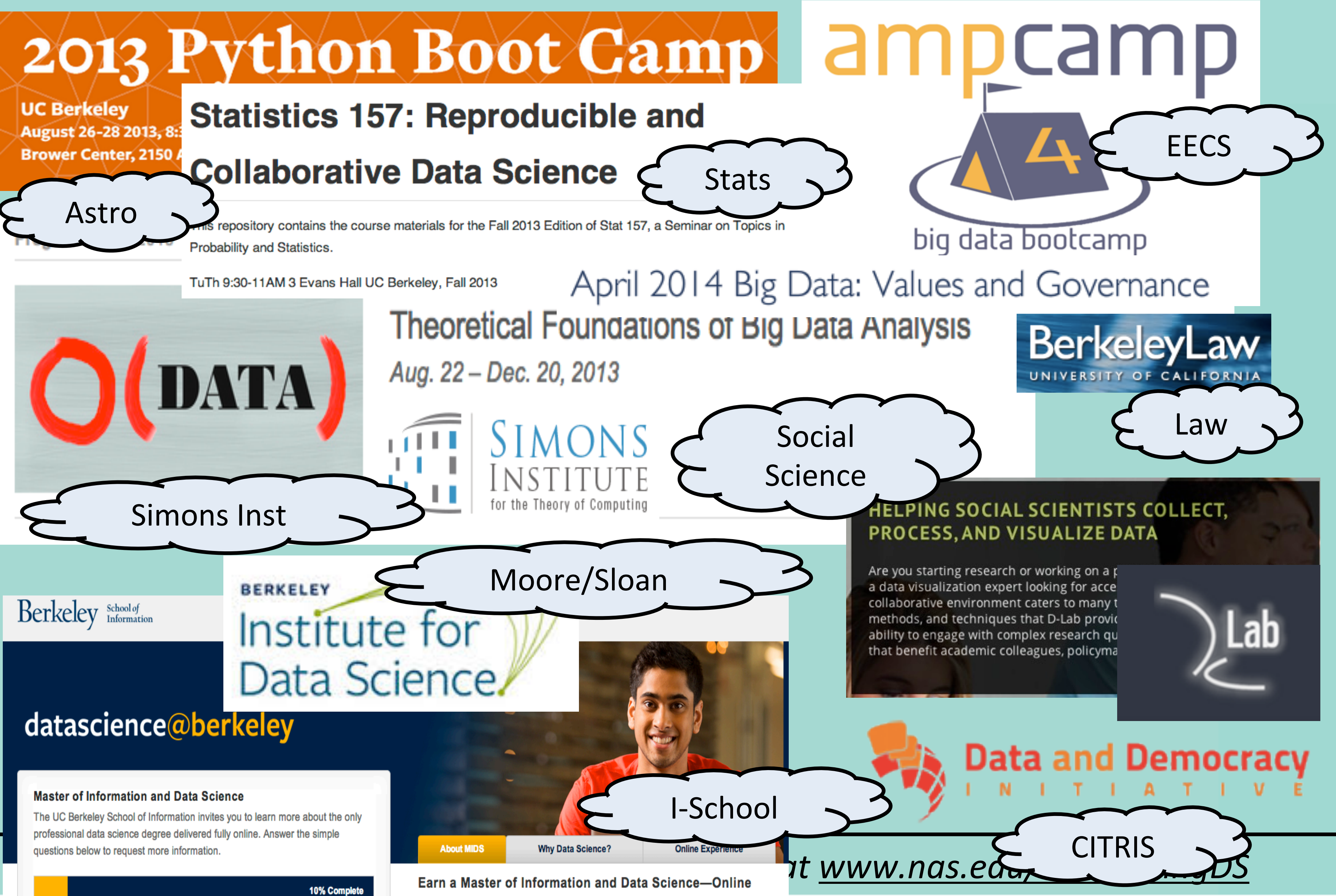
- Students get both degrees

Undergrad Data Science at Chicago

- Like most places – we've experienced dramatic increases in undergraduate enrollments in many CS and Stats classes (esp. Machine Learning)
- Initiatives are arising in Biological Sciences, Computational Social Sciences, Digital Humanities,…
- U Chicago's "Core" approach could provide an opportunity for curriculum development
- A campus-wide faculty committee is assessing and will make recommendations

WHERE DOES DATA SCIENCE LIVE ON A MODERN CAMPUS?

Nearly Everywhere! (e.g., Berkeley circa 2014)



2013 Python Boot Camp

UC Berkeley
August 26-28 2013, 8:
Brower Center, 2150

Statistics 157: Reproducible and Collaborative Data Science

This repository contains the course materials for the Fall 2013 Edition of Stat 157, a Seminar on Topics in Probability and Statistics.

TuTh 9:30-11AM 3 Evans Hall UC Berkeley, Fall 2013

April 2014 Big Data: Values and Governance

Theoretical Foundations of Big Data Analysis

Aug. 22 – Dec. 20, 2013

HELPING SOCIAL SCIENTISTS COLLECT, PROCESS, AND VISUALIZE DATA

Are you starting research or working on a p
a data visualization expert looking for acce
collaborative environment caters to many t
methods, and techniques that D-Lab provid
ability to engage with complex research qu
that benefit academic colleagues, policyma

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EECS
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Social Science
Simons Inst
Moore/Sloan
I-School
CITRIS

Some Big Issues in DS Education

- Establishing Data Science as a Discipline
  - Came from industry – not driven by academia
  - Unique intellectual foundations of Data Science?
  - Need scientific culture: e.g., Journals, Conferences
  - Training vs. undergraduate education
- Where on campus should DS be taught?
  - Department of Data Science? School of Data Science? Everywhere?
  - What departments should contribute? drive it?
- To whom
  - All Undergrads? (see Berkeley's "Data Science 8")
  - Certificates?, Minors?, Majors?
- How to manage the "Hype Cycle"?
  - Everyone wants a piece of it
  - Also, some skepticism

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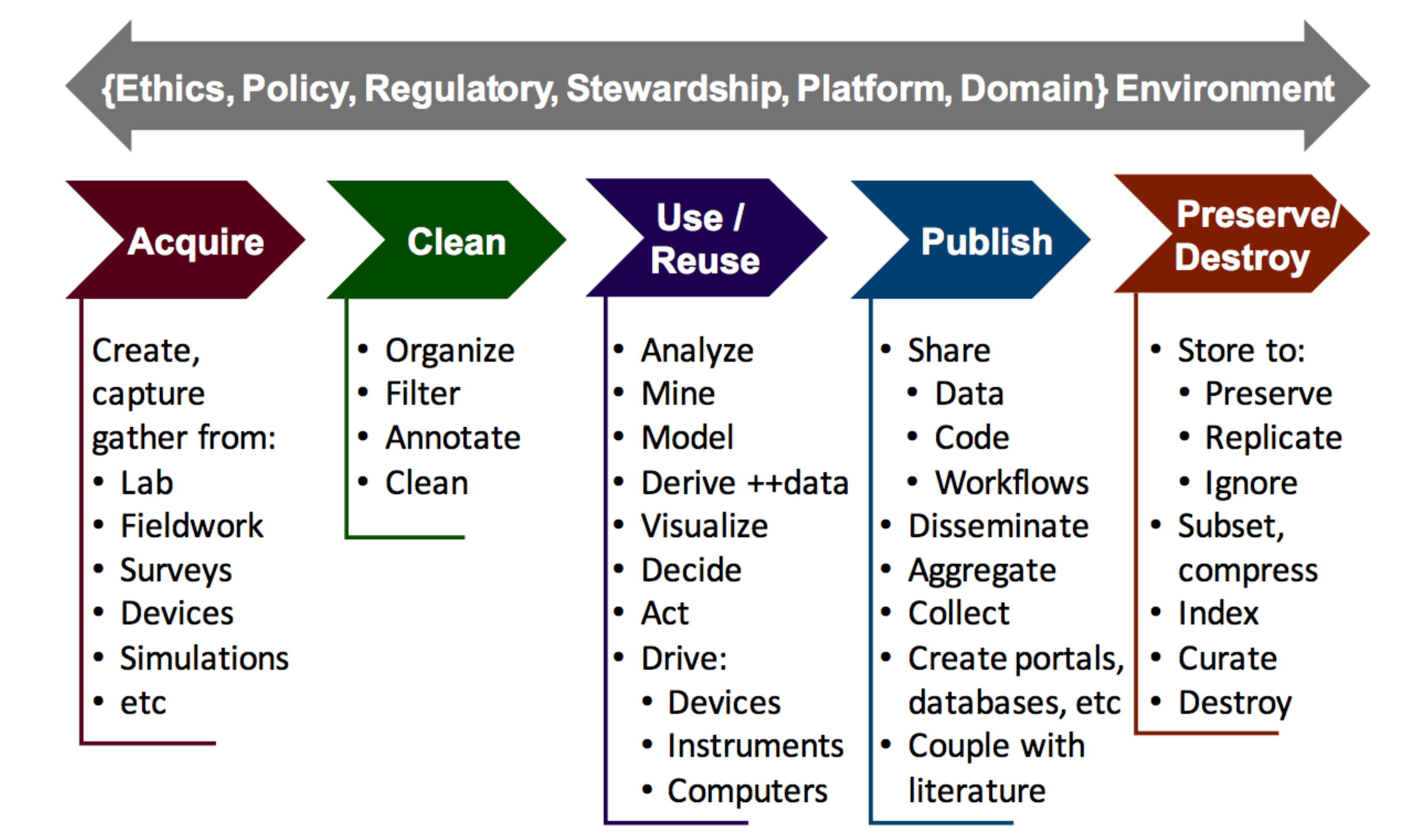
A Lifecycle View of Data Science



{Ethics, Policy, Regulatory, Stewardship, Platform, Domain} Environment

Acquire

Create, capture gather from:

- Lab
- Fieldwork
- Surveys
- Devices
- Simulations
- etc

Clean

- Organize
- Filter
- Annotate
- Clean

Use / Reuse

- Analyze
- Mine
- Model
- Derive ++data
- Visualize
- Decide
- Act
- Drive:
  - Devices
  - Instruments
  - Computers

Publish

- Share
  - Data
  - Code
  - Workflows
- Disseminate
- Aggregate
- Collect
- Create portals, databases, etc
- Couple with literature

Preserve/ Destroy

- Store to:
  - Preserve
  - Replicate
  - Ignore
- Subset, compress
- Index
- Curate
- Destroy

from the National Science Foundation CISE AC Data Science Report

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Data Science ≠ CS + Statistics

- In general – Data as a First-Class Concept
- Structure: Schema-on-read and Data Lakes (DataSpaces)
- Data Science Lifecycle
- Safe Data Science
    - “end-to-end” Bias Mitigation
    - Ethics and Data Privacy
    - Communicating results and influencing decisions
- Foundations & Methodologies vs. current tool set
- Note: DATA SCIENCE ≠ BIG DATA
    - Much can be taught on laptops
    - Scalability adds further issues and tradeoffs

Some Declared Data Science Majors

- Michigan: joint EECS (CoE) and Stats in LSA (Literature Science and Arts
- Ohio State: Data Analytics Major – joint CS/Stats – both in A&S with “Curricular partnerships”: Eng, Med, Business
- Penn State: “Data Sciences” – Colleges of Info Sys, Eng and Science – core, 1 of 3 concentrations, capstone project
- Purdue (fall 2017): Joint CS+Stats – (Eng and Coll of Sciences)
- U Rochester: CS+Stats+advanced coursework in an application area
- Yale: “Department of Stats and DS” – major approved (March 2017)

My Personal Take

- Data Science by necessity must span existing academic boundaries
- A "one size fits all" approach will not work
  - Some students need training and tools
  - Other students will drive the discipline forward
- Modern university structures are not optimized for such fields
- Widespread enthusiasm and interest provides an opportunity to innovate and collaborate across campus

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