Quantitative Cyber-Security

Colorado State University

Yashwant K Malaiya

CS559

Course Introduction

CSU Cybersecurity Center
Computer Science Dept

Wish we were there!

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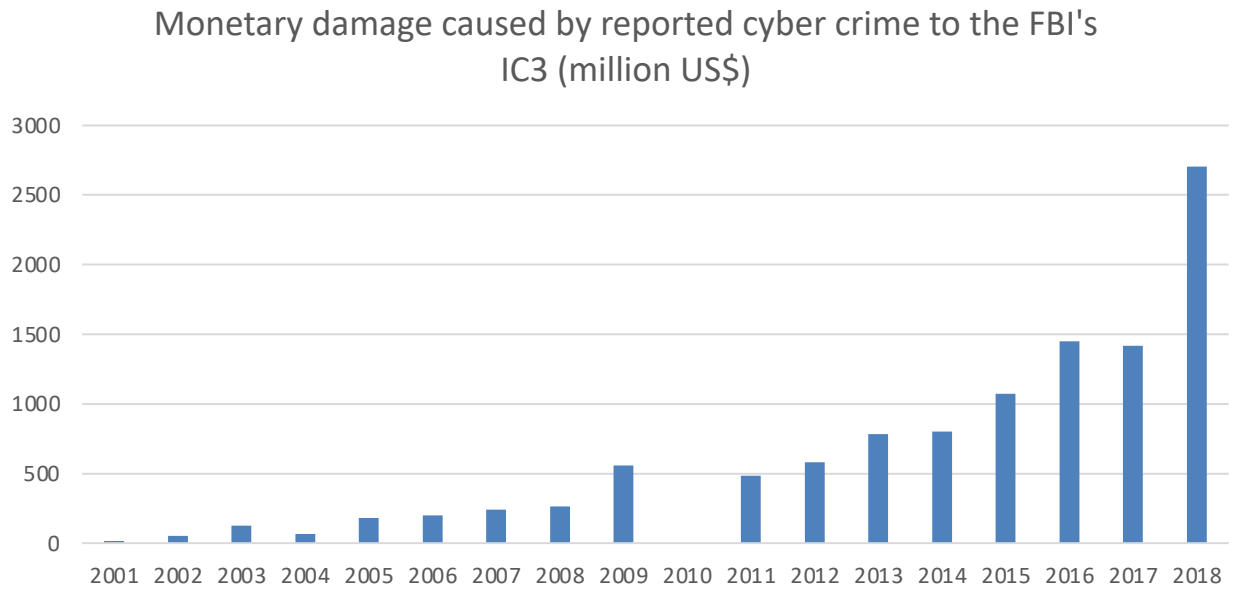
About the course

- **Quantitative and algorithmic view of cyber-security**
- **Intended for students from**
  - **computer science**
  - **engineering and business**
- **One semester graduate course**
  - **On-campus sections**
  - **Distance section**
  - **Mostly identical work requirements, however with some individual section optimization**
- **Course materials:**
  - **Lectures slides, videos**
  - **linked reading materials**
- **Evaluation:**
  - **on-line quizzes, assignments**
  - **Exams: Midterm, Final**
  - **term project: reearch**
  - **Interaction**
- **Technology requirement: use of excel, some open-source tools**

Cyber crime losses



- **FBI's Internet Crime Complaint Center (IC3) (2001-2018)**
- **Cybersecurity Ventures predicts cybercrime will cost the world**
  - **in excess of $6 trillion annually by 2021**
  - **up from $3 trillion in 2015**
  - **greatest transfer of economic wealth in history**
  - **more profitable than the global trade of all major illegal drugs combined.**

* 2010 data missing

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ABOUT ME: Yashwant K. Malaiya

- My Research approach
  - Explore what has not been examined
  - Concepts contributed: Antirandom testing, Detectability Profile, New Vulnerability Discovery models, new Software reliability models

Areas in which I have published:

- Computer security
  - Vulnerability discovery
  - Risk evaluation
  - Assessing Impact of security breaches
  - Vulnerability markets
- Hardware and software
  - Testing & test effectiveness
  - Reliability and fault tolerance
- Results have been used by industry, researchers and educators

About me

- Teaching
  - Computer Organization (CS270)
  - Operating systems (CS370 on-campus/on-line)
  - Computer Architecture (CS470 on-campus/on-line)
  - Fault tolerant computing (CS530 on-campus/on-line)
  - Quantitative Security (CS599 New! on-campus/on-line)
- Professional
  - Organized International Conferences on Microarchitecture, VLSI Design, Testing, Software Reliability
  - Computer Science Accreditation: national & international
  - Professional lectures
  - Advised more than 65 graduate students ..

Contacting us

- Professor: Yashwant Malaiya
  - Computer Science (CSB 356) but because of Covid-19 ..
- GTA: Ujwal Srinivas
  - Office Hours: TBD email/MS Teams
- Preferred e-mail address cs559@cs.colostate.edu
  - The subject should start as CS559: …
- Platforms:
  - Canvas https://canvas.colostate.edu
    - Used for videos. quizzes, project, exams
  - MS Teams: Interactive sessions, GTA and me

Topics we will cover in CS 599

1. Introduction: state, terms, concepts
2. Risk: breach likelihood and breach cost, scales
3. Probability and modeling
4. Vulnerabilities: taxonomy, life cycle, markets
5. Metrics, data bases
6. Attack types
7. Risk components:
    1. Breach likelihood components
    2. Breach cost components
8. Testing: coverage and effectiveness
9. Risk mitigation
10. Emerging issues and trends

Books and resources

- Required text-books: none
- will also use materials from other sources including
  - Research publications
    - You have access to CSU library digital resources (IEEE Explore/ACM/ScineceDirect etc)
    - Off campus access
  - Government, vendor and expert reports
  - System Documentation, articles, news etc.
  - Vulnerability related Data-bases
  - Selected Books

Grading

- Quizzes, Assignments, participation 30%
  - Quizzes 15%
  - Assignments 5%
  - Participation 10%
- Exams 30%
  - Midterm 20%
  - Final 10%
- Project: 40%
  - Topic search/proposal, Progress report 15% of project
  - Presentations & interaction 25%
  - Final report 60%

Grading

- Default dividing lines:
  - **≥ 98 is an A+, Near perfect**
  - **≥ 90 is an A, Excellent**
  - **≥ 88 is an A-, Very good**
  - ≥86 is a B+, Good
  - ≥80 is a B, Good enough
  - ≥78 is a B-, ≥76 is a C+, ≥70 is a C, ≥60 is a D, and <60 is an F.
- I will not cut higher than this, but I may cut lower.

Evolution of Cyber-security subfields

- Cyber-security field has several subfields. There are individuals and organizations that are experts in their subfield.
- The subfields have evolved separately, with specialists becoming experts in specific subfields, using their own terminology and framework.
- Inconsistent terminology leads to increased effort needed to understand developments and to cross-link them.
- Cyber-security is an emerging field, but there are well developed disciplines that are related:
  - Testing (hardware/software)
  - Fault tolerance (systems/hardware/software/network/data)
  - Reliability and risk evaluation (Quantitative/qualitative)
  - Investments and insurance (economic issues)
- Is it possible to connect different perspectives using a single framework?

Need for well-defined terminology

- In cyber-security field, some key terms are often used in a very ad-hoc manner.
- Consider for example the term ***risk*** a key concept.
- ***Risk*** may refer to
  - Attack types: "Ransomware, Social Engineering, Vendor Exposure"
  - "Cyber risk = probability of threat exploiting weak point of assets"
  - "Risk: The effect of uncertainty on objectives"
  - Etc.
- Which is the right definition of the term ***risk***?

Collaborative Learning

An old saying

आचार्यात् पादमादत्ते पादं शिष्यः स्वमेधया।
पादं सब्रह्मचारिभ्यः पादं कालक्रमेण च।।

Trans: 1. A student learns a quarter from his teacher, 2. another quarter using his own intelligence, 3. receives yet another quarter from his classmates and 4. the quarter in due course of time.

Introductions

Can each of you briefly briefly introduce yourself?

- First and last name
- Where you are from (mention city if it is a large country)
- What are you doing here? (major/year)
- Technical (and personal, if you like) Interests

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Course Outline

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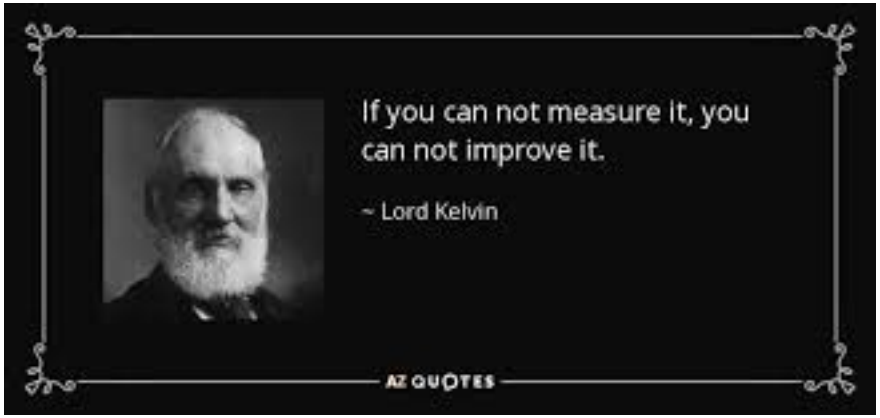
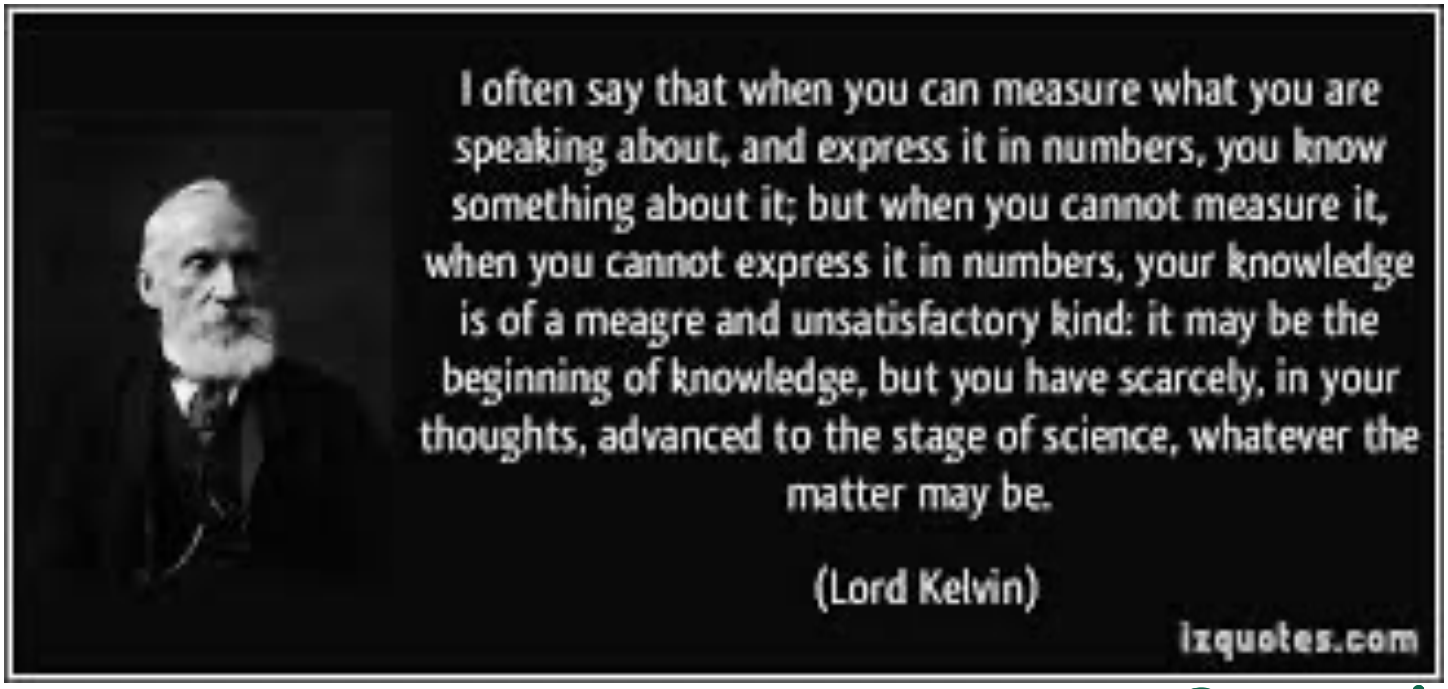
Lord Calvin





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Course Outline 1

Note: Subject to dynamic refinements

Course Introduction/Background:

- Introduction, Outline, Current state
- Key terms, Access control, Security framework

Risk:

- as the product of breach likelihood and breach cost and their components, conflicting definitions of risk
- Linear/logarithmic scales, Risk Matrix, Time-frame: per event (single breach) vs per year (annual loss expectancy).
- Insurance

Course Outline 2

Probability/distributions/Modeling

- A review of essential concepts from probability, conditional probabilities, Bays` rule
- Common distributions used in risk evaluation, Monte Carlo simulation
- Modeling approaches, Regression
- Combinatorics (Ciphers and password)

System Security Architecture: Networked system components, placement of protection schemes

Course Outline 3

Vulnerabilities

- Types: Software: defect vs vulnerabilities, System/network/configuration, Social engineering: exploitation of human weaknesses
- Life cycle: Introduction, discovery, disclosure, patching, exploitation.
- Vulnerability Discovery process in individual and evolving programs, Longer-term trends
- Metrics: Metrics, CVSS v2/v3 metrics and scores., Temporal (patches and exploits), Environmental metrics CVSS,
- Databases: NVD, CVEDetails, VulnDB, ExploitDB

Course Outline 4

Testing for bugs and vulnerabilities

- Testing as exercising input or structure space, Testing Profiles
- Coverage metrics, Fuzzing and Pen Testing
- Probabilistic vs deterministic testing, Test effectiveness

Research methodology

- Potential sources of information
- Identifying research threads and trends
- Information extraction and consolidation
- Assessing promise of a research direction

Course Outline 5

Attacks

- Attack types, Intrusion detection, Mitre ATTack framework
- **Breach likelihood components:** Vulnerability presence, Breach Probability, Vulnerability exploitability, and reachability, Motivation/skill/tool support of potential adversaries, Impact of management policies.
- **Breach cost components:** Investigation costs, crisis mitigation costs, cost of sanctions and lawsuits. Question of insurance coverage, tax breaks. Longer-term costs: loss of reputation and business opportunity**.**
- **Costs to a government/nation:** loss of industrial IP, defensive secrets, tempering with national infrastructure or defenses

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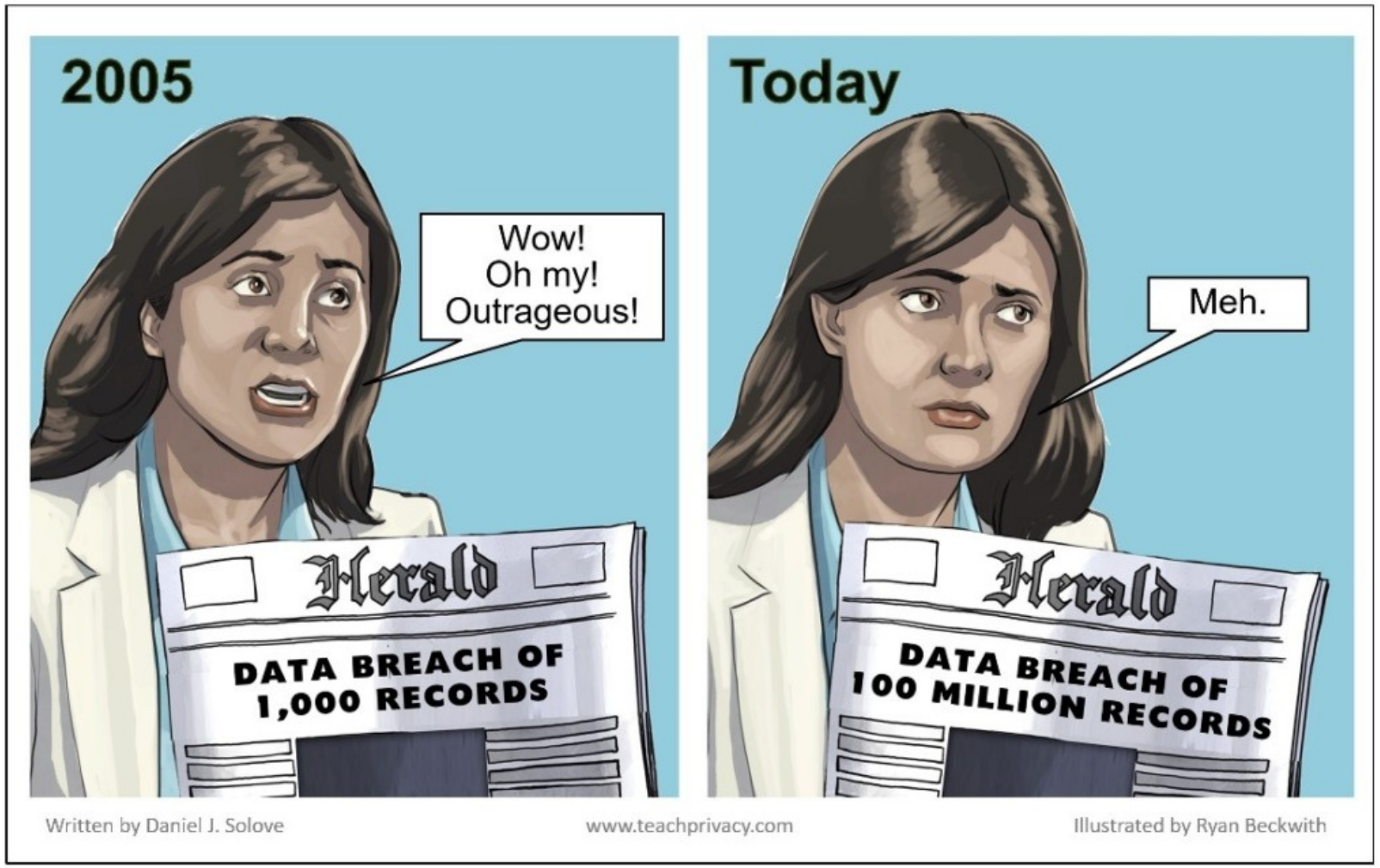
Recent Security Statistics

CSU Cybersecurity Center
Computer Science Dept

What can you do with numbers?

- Assess relative magnitude of problems
  - Even if the data is limited or anecdotal
- Construct models
  - If there is enough data
  - Make projections
  - Understand causes and engineer for desired behavior
- Where to find data?
  - Someone has already compiled data
  - Doing experiments to collect data
  - Search and search for pieces of data. You migt b able to link them.

Progress in Cyber-security



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Cyber Security Statistics- 2019

- **Breaches:**
  - **in most cases, it takes half a year to detect a data breach.**
  - There were 8,854 recorded breaches between January 1, 2005 and April 18, 2018. Price per record ranging anywhere from $120-$600
  - **31% of organizations have experienced cyber attacks on operational infrastructure.**
  - 43% of all cyber attacks are aimed at small businesses. In 2017, 61% of data breach victims were companies with less than 1000 employees.
  - Around 50% of the risk companies face, come by way of having multiple security vendors!
  - **Just 38% of global organizations claim that they are equipped and able to handle a complex cyber attack**

Cyber Security Statistics- 2019

- **Phishing:**
  - **91% of attacks launch with a phishing email**
  - 30% of U.S. users open phishing emails.
  - **12% of those who opened phishing emails later opened the infected links or attachments.**
  - 85% of all attachments emailed daily are harmful for their intended recipients.
  - In the last year, 76% of businesses reported that they had been a victim of a phishing attack.
  - 38% of malicious attachments are masked as one Microsoft Office type of file
- **Human errors:**
  - **65% of companies have over 500 employees that have never changed their password.**
  - **95% of data breaches have cause attributed to human error**

Cyber Security Statistics- 2019

- **Attacks**
  - **Over 24,000 malicious mobile apps are blocked from the various app stores each day.**
  - IoT attacks were up by 600% in 2017.
  - DDoS attacks account for 5% of monthly traffic related to gaming.
  - **Around 60% of malicious web domains are associated with spam campaigns.**
  - **Cyber criminals managed to exploit the credit cards of 48% of Americans back in 2016.**
- **Malware**
  - There was an 80% increase in malware attacks on Mac computers in 2017.
  - **75% of the healthcare industry has been infected with malware at some point in time.**
- **Ransomware**
  - **Ransomware attacks are growing more than 350% annually**.
  - The damage costs of ransomware will rise to $10 billion in 2019.
  - A business falls victim to a ransomware attack every 13.275 seconds.

Cyber Security Statistics- 2019

- **Weaknesses:**
  - Of all files, 21% remain completely unprotected.
  - Reported system vulnerabilities went up by 16% in 2017.
- **Costs and Opportunities**
  - **$2.4 million is the average cost of a malware attack in 2017.**
  - **The global cost of online crime is expected to reach $6 trillion by 2021.**
  - **Cybersecurity expenditures are expected to reach $1 trillion by 2024.**
  - The annual cost of cybercrime damages is expected to hit $5 trillion by 2020.
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  - The annual cost of cybercrime damages is expected to hit $5 trillion by 2020.
  - Cybersecurity expenditures are expected to reach $1 trillion by 2024.
- **Jobs**
  - Cybersecurity job postings are up 74% over the past five years.
  - There are over 300,000 unfilled cybersecurity jobs in the United States, with the demand rising each year.
  - **By 2021, the number of unfilled cybersecurity jobs is expected to balloon to 3.5 million**.
  - Cybersecurity job postings are up 74% over the past five years.

https://www.cyberdefensemagazine.com/cyber-security-statistics-for-2019/

Course Outline 6

Risk mitigation

Reducing the breach likelihood, Reducing the breach cost.

Security Economics, Security investment ROI, Attack surfaces and connectivity, Threat containment strategies and their effectiveness.

Emerging topics

Vulnerability markets: Legitimate (for example rewards programs), Gray (vulnerability brokers) and black markets, Potential buyers and sellers of Zero-day vulnerabilities and exploits

People: Well known Vulnerability finders/cyber criminals

Readings/Discussion

- The course will involve reading some assigned articles and discussing them
  - May involve looking up background and recent developments

Term Project

- Term project: You will choose a topic from a given list. Other topics may be permitted by the instructor. Need to be aligned with the objectives of the class.
- Project will involve
  - Preliminary research to identify the sources of information and the topic/problem to be investigated.
  - Proposal (9/30), Progress report (01/28), Final report (12/9)
    - At least some original ideas
    - Presentations required
  - Presentations and discussions are required
  - Peer reviews and comments needed