http://elec3004.com

An Introduction to Digital Linear **Systems: Signals & Controls**

Welcome!

ELEC 3004: **Systems**: Signals & Controls

Dr. Surya Singh

Lecture 1 [V2]

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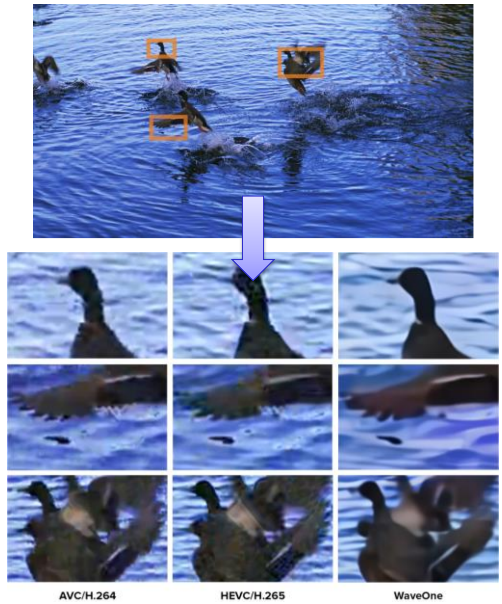
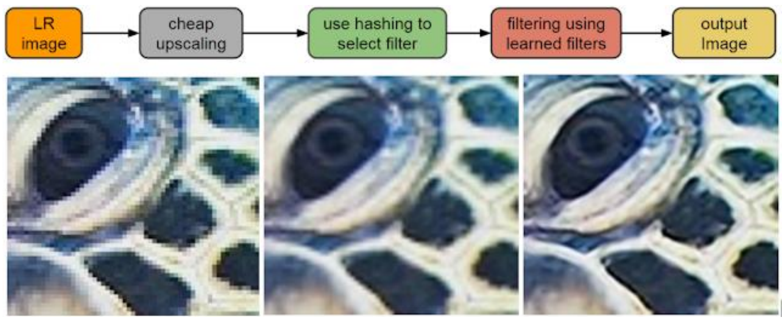
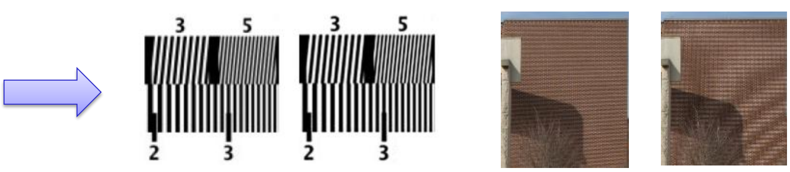
http://robotics.itee.uq.edu.au/~elec3004/

February 27, 2019

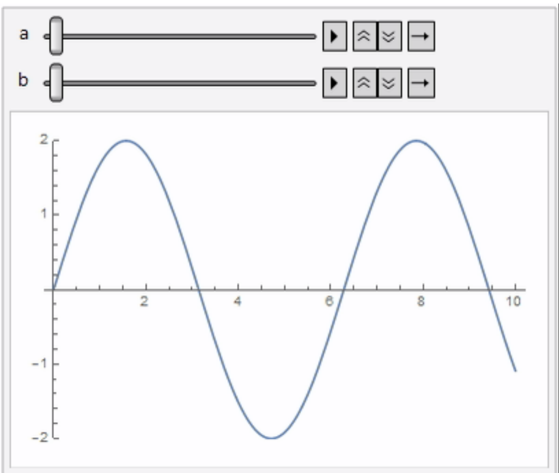


Ref: Rippel, Nair, Lew, *et al.*, Learned Video Compression, arxiv: 1811.06981, **16 Nov 2018**
URL: http://www.wave.one/video-compression





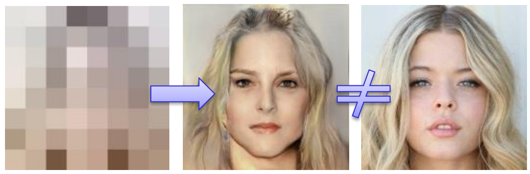
Ref: Google RAISR, Wikipedia, Aliasing
URL: https://ai.googleblog.com/2016/11/enhance-raisr-sharp-images-with-machine.html



Mathematica:

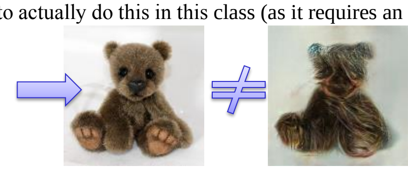
```
waveani = Animate[Plot[Sin[a x] + Sin[b x], {x, 0, 10}, PlotRange -> 2], {a, 1,  5}, {b, 1, 5}, AnimationRunning -> True]
```

Ex_5: Magnification of Faces by a Factor of 64×



Input (8x8) | WaveOne output (512x512) | Original (512x512)

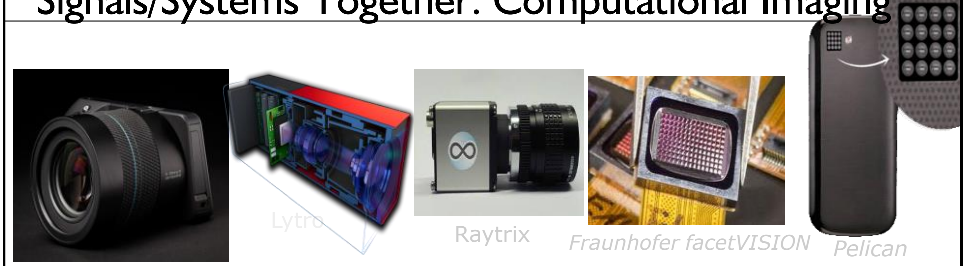
- PS. While we cover the theory why this is hard ☺,
  We don't cover how to actually do this in this class (as it requires an **extensive** face database) ☹

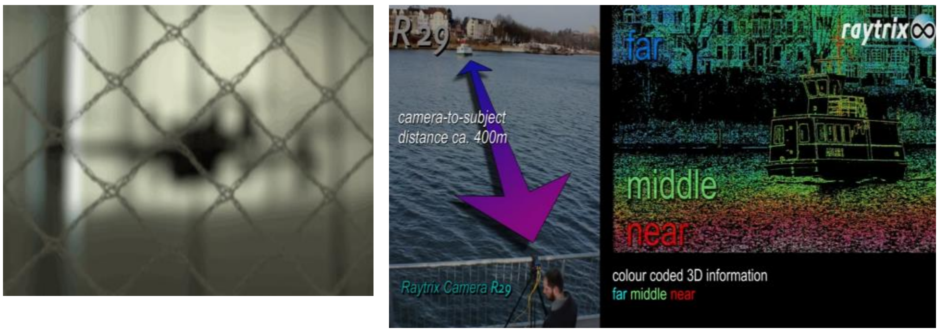


- However, for a **great review** please see:
  Baker, S., & Kanade, T. (**2002**). "Limits on super-resolution and how to break them." *IEEE Transactions on Pattern Analysis & Machine Intelligence*, (9), 1167-1183.
  DOI: [http://dx.doi.org/10.1109/tpami.2002.1033210]

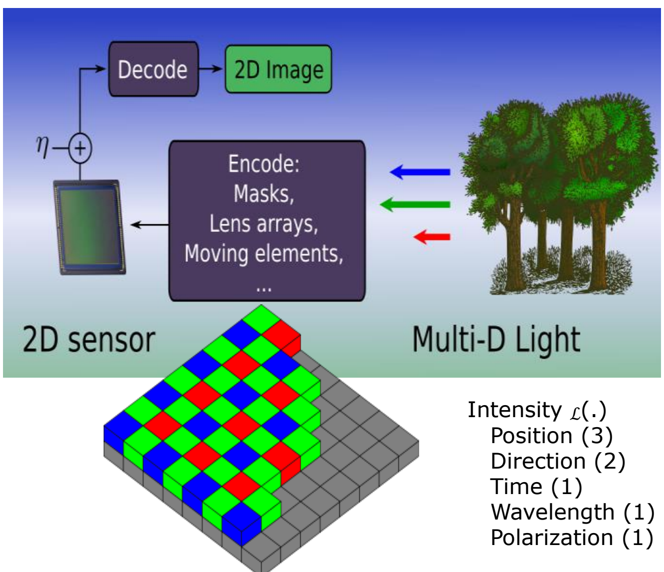
URL: http://www.wave.one/face-compression (**September 2018**)

Signals/Systems Together: Computational Imaging





Example$_7$: Computational Imaging

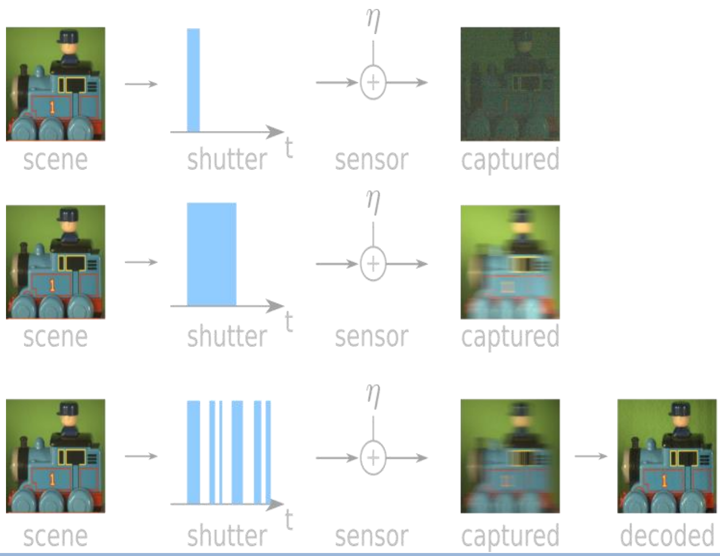


Intensity $\mathcal{L}(.)$
- Position (3)
- Direction (2)
- Time (1)
- Wavelength (1)
- Polarization (1)

Another Example: Computational Imaging

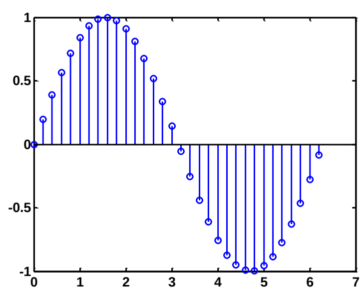
- Flutter Shutter

[raskar2006]



What's a Signal?

≡ *A set of data or* ***information***



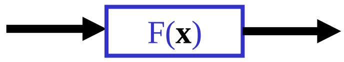
- Can be a function of in **space** and/or **time**
- Various types: electrical, economics, dating, etc.
- Data → "information" is a process of understanding its structure/ forms:

$$\sin(\omega t)$$

What is a System?

≡ A **process** (function) by which information (signals) are modified so as to extract additional information from them

- Systems modify the signal(s) to yield a new result (also a signal)
- Can be of various forms: electrical, mechanical, etc.



Systems Can Be Simpler Than You Think

- B747
  - level flight,
  - 40000 ft, 774 ft/sec …

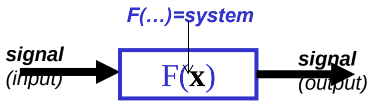
$$\begin{bmatrix} \dot{u} \\ \dot{v} \\ \dot{q} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} -.003 & .039 & 0 & -.322 \\ -.065 & -.319 & 7.74 & 0 \\ .020 & -.101 & -.429 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} u - u_w \\ v - v_w \\ q \\ \theta \end{bmatrix} + \begin{bmatrix} .01 & 1 \\ -.18 & -.04 \\ -1.16 & .598 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \delta_e \\ \delta_t \end{bmatrix}$$

  - u, w: horizontal/vertical velocity
  - q, θ: orientation & pitch rate
  - δe, δt : elevator and thrust commands

Source: Boyd, Stanford EE263 Lecture 14 (Slide 14-4)

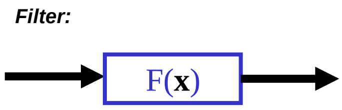
Signals and Systems Together

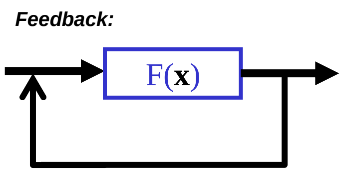
- A **signal** can be seen as that which goes in and out of a **system**



Signals and Systems Together

- A **signal** can be seen as that which goes in and out of a **system**
- **Signal Processing / "Filters" :** can be seen as a open-loop system
- **Feedback Control:** can be viewed as the case where the output signal **shapes** the input signal





Introducing
ELEC3004/7312

Website: http://robotics.itee.uq.edu.au/~elec3004/

Schedules and Locations:

- **Lectures:**
  - **Wednesdays** from **10:05 am – 12:00 noon**
  - Social Science Building (24) – Room **S304**
  - **[**Here! ☺**]**

&

  - **Fridays** from **4:05 -- 5:30 pm**
  - Parnell (Physics) Building (07) – Room **234**

- It starts at 10:05a (or 4:05p on Fridays) ➔ 🚶 Relax!

Schedules and Locations: **Tutorials**

- **Tutorials: EVEN Weeks (Starting on Week 2)**
  SIX parallel sessions -- **Please come to your assigned one**.
  - Alternate attendance is at tutor discretion and must be arranged in advance

- Sessions are:
  - **Wednesday 4:00p--6:00** in Hawken - Room S202
  - **Thursday 9:00a--11:00** in Hawken - Room S202
  - **Thursday 12:00n--2:00** in Hawken - Room S202
  - **Thursday 2:00p--4:00** in Hawken - Room S202
  - **Thursday 4:00p--6:00** in Hawken - Room S202
  - **Friday 2:00p--4:00** in Hawken - Room S202

- ~ 1.5 hours

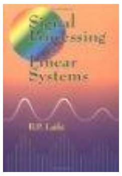
Schedules and Locations: **Labs**

- **Prac / Lab Sessions: ODD Weeks (Starting Week 3)**
  - Six parallel sessions -- **Please come to your assigned one**.
  - Alternate attendance is at tutor discretion and must be arranged in advance
- Sessions are:
  - **Wednesday 4:00p--6:00** in Hawken - Room S202
  - **Thursday 9:00a--11:00** in Hawken - Room S202
  - **Thursday 12:00n--2:00** in Hawken - Room S202
  - **Thursday 2:00p--4:00** in Hawken - Room S202
  - **Thursday 4:00p--6:00** in Hawken - Room S202
  - **Friday 2:00p--4:00** in Hawken - Room S202
- ~ 2 hours

Lecture Schedule:

Week	Date	Lecture Title
1	27-Feb	Introduction
	1-Mar	Systems Overview
2	6-Mar	Systems as Maps & Signals as Vectors
	8-Mar	Systems: Linear Differential Systems
3	13-Mar	Sampling Theory & Data Acquisition
	15-Mar	Aliasing & Antialiasing
4	20-Mar	Discrete Time Analysis & Z-Transform
	22-Mar	Second Order LTID (& Convolution Review)
5	27-Mar	Frequency Response
	29-Mar	Filter Analysis
6	3-Apr	Digital Filters (IIR) & Filter Analysis
	5-Apr	Digital Filter (FIR)
7	10-Apr	Digital Windows
	12-Apr	FFT
8	17-Apr	Active Filters & Estimation & Holiday
	19-Apr	Holiday
	24-Apr	
	26-Apr	
9	1-May	Introduction to Feedback Control
	3-May	Servoregulation/PID
10	8-May	PID & State-Space
	10-May	State-Space Control
11	15-May	Digital Control Design
	17-May	Stability
12	22-May	State Space Control System Design
	24-May	Shaping the Dynamic Response
13	29-May	System Identification & Information Theory
	31-May	Summary and Course Review

Reference Texts:



B. P. Lathi
Signal processing and linear systems
1998
[TK5102.9.L38 1998]

João Hespanha
Linear Systems Theory,
2009
[UQ Ebooks]

- Yes!
You may use the Internet!!
  – Khan Academy
  – Wikipedia
  – YouTube
  – & **Google Scholar** Too!

- This field is vast & there are countless references present

The Point of the Course

- Introduction to terminology/semantics
- An appreciation of how to frame problems in a linear systems engineering context
- Modeling and learning assumptions/when to trust the model
- Ability to identify critical details from the problem

➔ It's a **shortcut** …
Once you see that a system is **"linear"**
you can then apply the raft of
"linear systems" tools
(time & frequency analysis) to them
without having to do all the analysis from scratch

Not the Point of the Course

- Get good grades
- Just do homework
- Memorize pointless facts
- Rote "learning" of material with no comprehension
- Ask yourself, is the wonder still there?

Lots of Stuff To Cover…

- Systems
- Signal Abstractions
- Signals as Vectors / Systems as Maps

- Linear Systems and Their Properties
- LTI Systems
- Autonomous Linear Dynamical Systems

- Convolution
- FIR & IIR Systems
- Frequency domain
- Fourier Transform (CT)
- Fourier Transform (DT)

- Even and Odd Signals
- Likelihood
- Causality

- Impulse Response
- Root Locus
- Bode Functions

- Left-hand Plane

- Frequency Response

- Discrete Time
- Continuous Time

- Laplace Transformation
- Feedback and Control
- Additional Applications

- Linear Functions
- Linear Algebra Review
- Least Squares
- Least Squares Problems
- Least Squares Applications
- Matrix Decomposition and Linear Algebra
- Regularized Least Squares

- Least-squares
- Least-squares applications
- Orthonormal sets of vectors
- Eigenvectors and diagonalization
- Linear dynamical systems with inputs and outputs
- Symmetric matrices, quadratic forms, matrix norm, and SVD

- Controllability and state transfer
- Observability and state estimation

- And that, of course,
  Linear Systems are Cool! ☺

Assessment

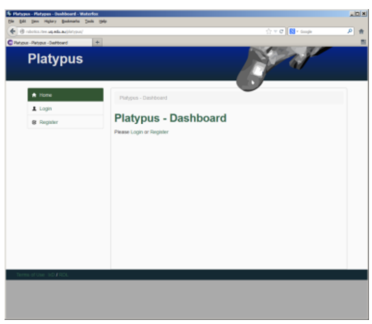
- **[Problem Set 1: An Introduction to Signals and Systems (20%)]** Due: March 29, 2019 at 23:59 AEST [end of week 4]

- **Problem Set 2: Sampling and Filters (Digital & Analog) (20 %)**
  Due: May 3, 2019 at 23:59 AEST [end of week 9]

- **Problem Set 3: Digital Feedback Control (20 %)**
  Due: May 24, 2019 at 23:59 AEST [end of week 12]

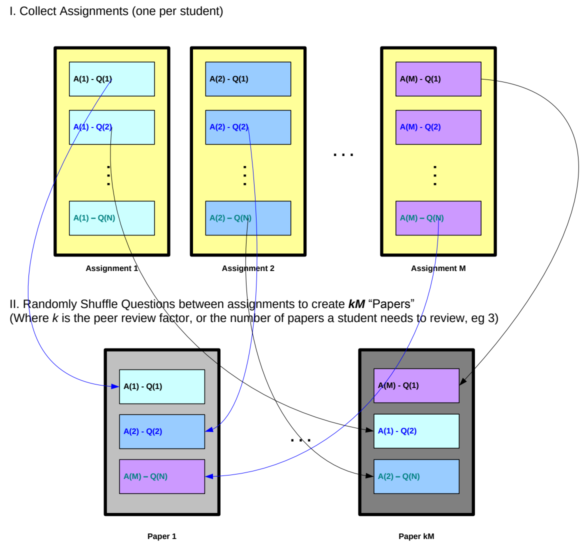
Platypus: Peer-review for Deliberate Practice/Learning

- **Peer-Review**
  - A **key** part of Engineering is being able to critically evaluate peer work (and give **good** feedback on it)
  - We **will** help teach you good habits of peer feedback



- **Question** (not Assignment) based random shuffling

Platypus: How does it work?



In Summary: Some Philosophy

- Let's start with Why …

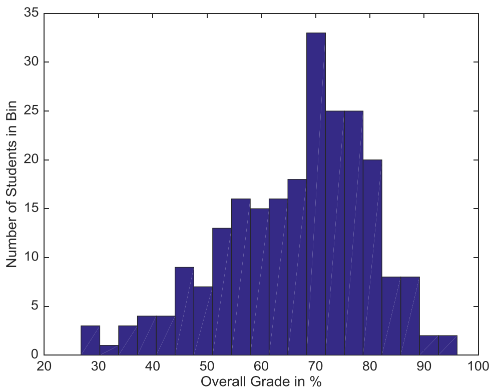
- To learn something is to teach it
  - The function of a teaching is not so much to cover the topics, but more to discover them

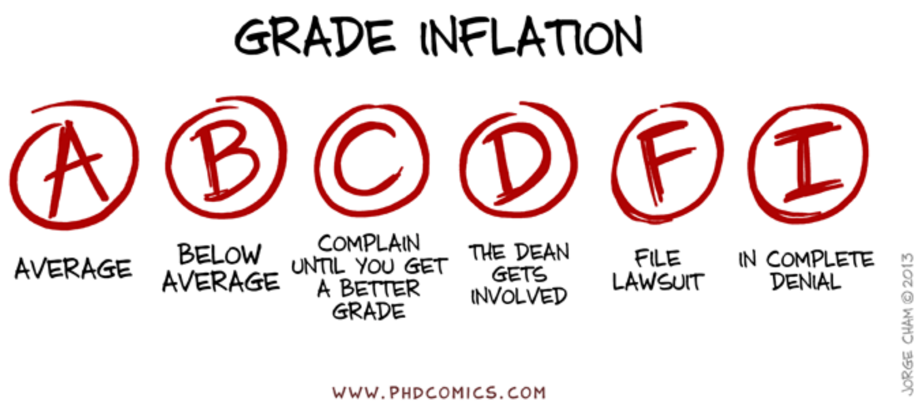
- It is actually <u>**more**</u> work for us!
  - We have to teach you how to reflect
    & then assess this as well as how to do the assignment

- It helps you understand it by giving you a different perspective
- We're a community
  - You (alone) can't do everything … that's why we work together
  - The notion of "free speech" ➔ Trust emerges → efficiency (η)

Last Year's Grade Statistics

- ~ 62 % received >4 and ~30% received D or HD
- Worry about **learning**, not about marks





I need a “7” for a Job!

The New York Times | http://nyti.ms/1jTJavh

SUNDAYREVIEW | OP-ED COLUMNIST

How to Get a Job at Google

FEB. 22, 2014

Thomas L. Friedman

MOUNTAIN VIEW, Calif. — LAST June, in an interview with Adam Bryant of The Times, Laszlo Bock, the senior vice president of people operations for Google — i.e., the guy in charge of hiring for one of the world’s most successful companies — noted that Google had determined that “G.P.A.’s are worthless as a criteria for hiring, and test scores are worthless. … We found that they don’t predict anything.” He also noted that the “proportion of people without any college education

Information: Size and Rate

A short novel	1 megabyte	1,000,000
All undergraduate textbooks	100 MB	100,000,000
An iPod	100 GB	80,000,000,000
A library floor of academic journals	100 GB	100,000,000,000
Print collections of Library of Congress	10 TB	10,000,000,000,00

Copying notes by hand	32 bits/second	32 bps
Speaking	230 bits/sec.	230 bps
Reading text	360 bits/sec	360 bps
Home internet connection	1-10 Mb/sec.	5,000,000 bps
Single optical fiber	40 Gb/sec.	40,000,000,000 bps

A short novel ≅ 1 Mbyte {
- 70 hours to copy
- 6 hours to read
- Less than 10 seconds to download

Taken from: *http://burikmodeldesign.com/search/How_Many_Bytes.htm*

Changes from 2017

1. Three Assignments (Peer-reviewed, Marks from Tutor)

2. Labs remain optional
   1. Concepts still overlap with class
   2. May be assessed on Assignments/Final Exam

3. No State-Space Control "crammed" in the end

4. I am still inspired by, but little less of,
   Boyd's EE263: *Introduction to Linear Dynamical Systems*

E-mail

- **elec3004@itee.uq.edu.au**

- Casper!
  - https://casper.ceit.uq.edu.au/courses/elec3004/

- [That's it!]
- {Not the instructors/tutors personally}

Communications: Some Expectations

- **Think carefully before using email**
- Please keep communication concise and polite
- Let me know if there are problems
  - During tutorials, before and after lectures
  - Student reps (Teaching and Learning Committee)
  - Consultation period: 4-6pm Thursday

Communications: Examples

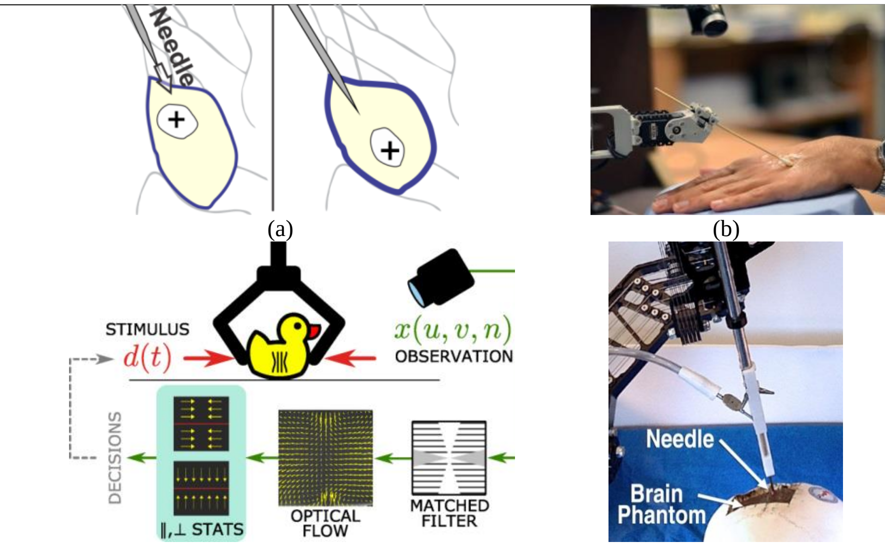
- Email 1:

```
To [ELEC3004],
I am currently signed up for the Tuesday afternoon
tutorial, T1, but this clashes with another subject in
which I have no movement. Is it possible for me to be
changed into the Wednesday morning tutorial, T2?
Thank You for your time.
Name signed,
student number
```

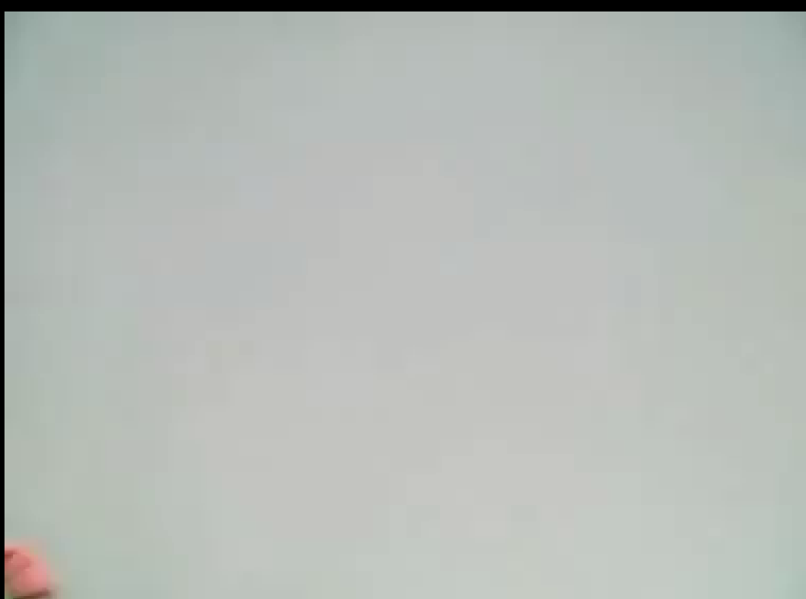
- Email 2:

```
S'up!! ☺
all T classes be the full, can't sign on ☹
```

About What I Do



(a) Lesion targeting **(b)** DermBot **(c)** Visual Deformable Object Analysis **(d)** Neurosurgical Robotics



Prere-***quiz***-ite Solutions ☺

Q1: Complex Solutions to Real Problems

Can an ODE with only real constant coefficients have a complex solution?

- Yes, because the coefficients do not give the solution, but rather setup an equation that instead gives a solution
- For example:

$$y'' + y = 0$$

- Has solutions:

$$e^{ix} \text{ and } e^{-ix}$$

Q2: Transfer Functions and the s-Domain [1]

Final Value Theorem

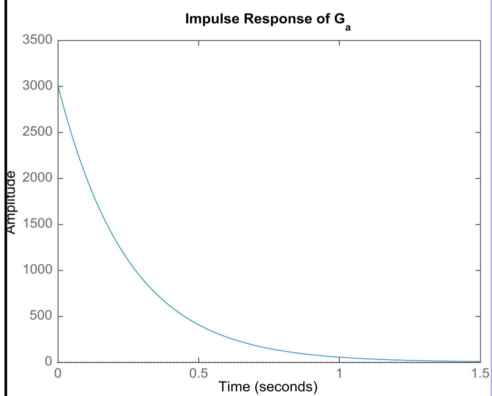
$$\lim_{t\to\infty} f(t) = \lim_{s\to 0} sF(s)$$

Latex Version:
$\lim_{t\to\infty} f(t) = \lim_{s\to 0} sF(s)$

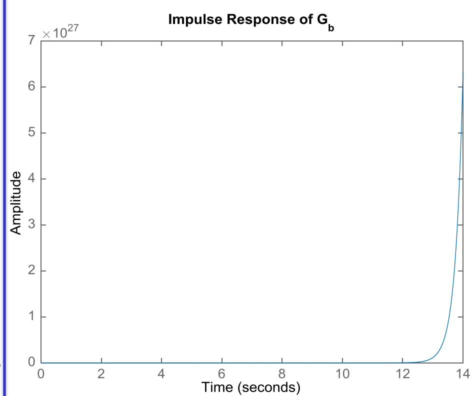
- For systems that are valid (i.e., stable):
  - Roots of the denominator of $\boldsymbol{H(s)}$ must have negative real parts.
  - $\boldsymbol{H(s)}$ must not have more than one pole at the origin.

Q2: Transfer Functions and the s-Domain [2]

- $G_a(s) = \dfrac{3004}{s+4}$

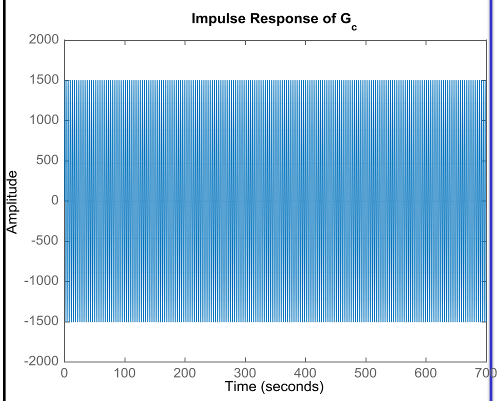


- $G_b(s) = \dfrac{3004}{s-4}$

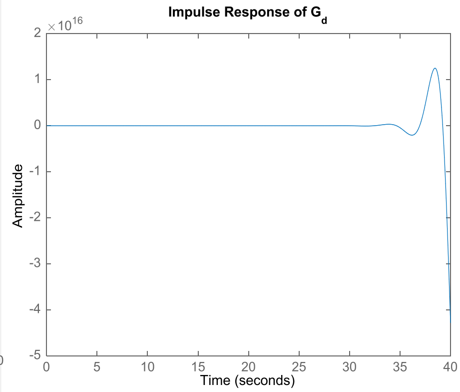


Q2: Transfer Functions and the s-Domain [3]

- $G_c(s) = \frac{3004}{s^2+4}$

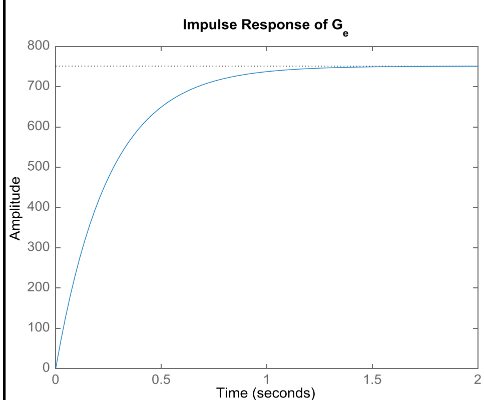


- $G_d(s) = \frac{3004}{s^4+4}$

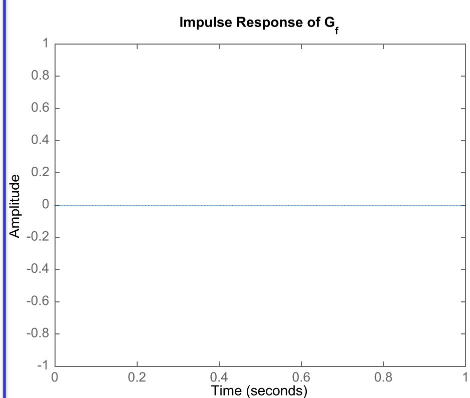


Q2: Transfer Functions and the s-Domain [4]

- $G_e(s) = \frac{3004}{s^2+4s}$

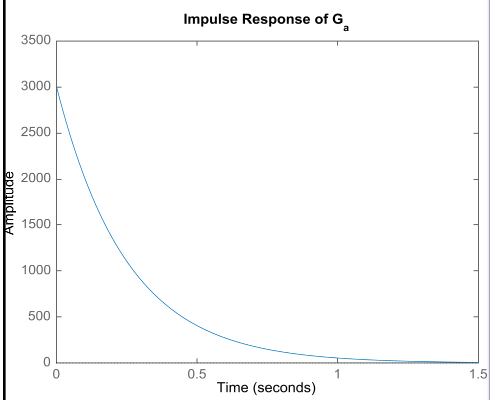


- $G_f(s) = \frac{3004}{4} = 751$
- Not a "dynamic system"

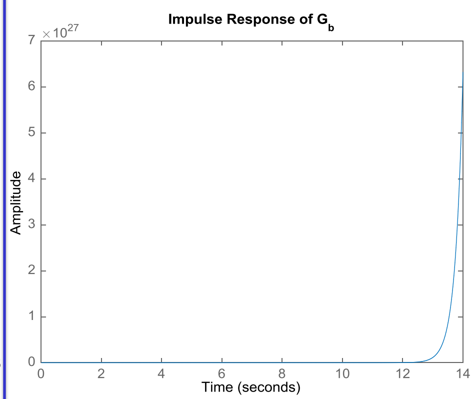


Q2: Transfer Functions and the s-Domain [2]

- $G_a(s) = \frac{3004}{s+4}$



- $G_b(s) = \frac{3004}{s-4}$



Q2: Transfer Functions and the s-Domain [5] Matlab Source for Graphs

```
%% ELEC 3004 Quiz 0 -- Q2
% Ga
a=[3004]; b=[1 4]; Ga=tf(a, b);  figure(10);
impulse(Ga);  title('Impulse Response of G_a');
% Gb
a=[3004]; b=[1 -4]; Gb=tf(a, b);  figure(20);
impulse(Gb); title('Impulse Response of G_b');
% Gc
a=[3004]; b=[1 0 4]; Gc=tf(a, b);  figure(30);
impulse(Gc); title('Impulse Response of G_c');
% Gd
a=[3004]; b=[1 0 0 4]; Gd=tf(a, b);  figure(40);
impulse(Gd); title('Impulse Response of G_d');
% Ge
a=[3004]; b=[1 4 0]; Ge=tf(a, b);  figure(50);
impulse(Ge); title('Impulse Response of G_e');
% Gf
a=[3004]; b=[4]; Gf=tf(a, b);  figure(60);
impulse(Gf); title('Impulse Response of G_f');
```

Q3: Free Determination

- False:

$$\det(A+B) \neq \det(A) + \det(B)$$

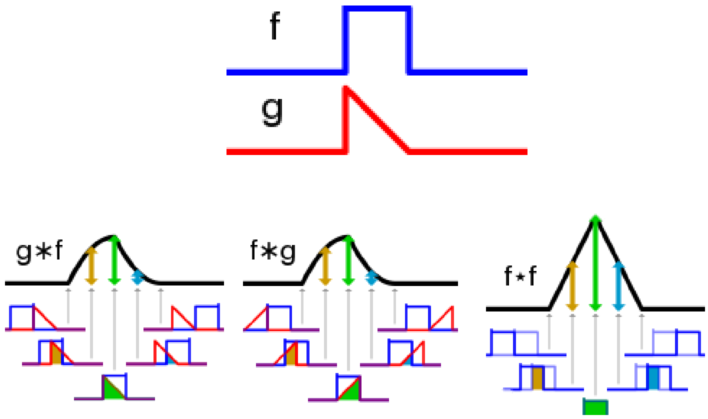
- True:

$$\det(AB) = \det(A) \cdot \det(B)$$

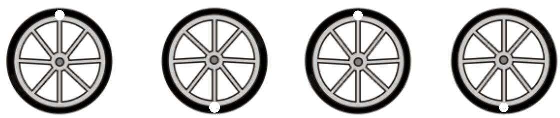
Q4: Free Determination : All TRUE

- True:
  $A = LU$: is a factorization that is basically an elimination
- True:
  If $\boldsymbol{A}$ is invertible, then the only solution to $\boldsymbol{Ax} = \boldsymbol{0}$ is $\boldsymbol{x} = \boldsymbol{0}$.
- True:
  Linear Equations ($Ax = b$) come from steady-state problems.
  eigenvalues ($Ax = \lambda x$) have importance in dynamic problems.

Q5: Convolution!: All TRUE



Q6: A Signal Re-volution!



Frame 1 Frame 2 Frame 3 Frame 4

A. It could be rotating either way (CW or CCW). The angular velocity is $\dot{\theta} = \frac{\Delta\theta}{\Delta t} = \left[\frac{(2n+1)\pi}{\frac{1}{25}}\right] \Rightarrow 12.5\ rev/second$

B. Speeds (m/s):

$$v = \omega \times r = 25\pi \frac{rad}{s} \cdot (0.32\ m) = 25.1 \frac{m}{s} = 90.5\ kmh$$

C. $\text{Speed}_{car} \stackrel{?}{=} \text{Speed}_{wheel}$:

- Straight line (no turning)
- Full traction
- No suspension effects …
- What is the **frame of reference**? Should be picked with care!

Next Time…

- We'll talk about System Models
- Review:
  - Phasers, complex numbers, polar to rectangular, and general functional forms.
  - Chapter 1 of Lathi
    (particularly the first sections on signals & classification thereof)
- Register on Platypus
- Try the practise assignment (will be posted soon)