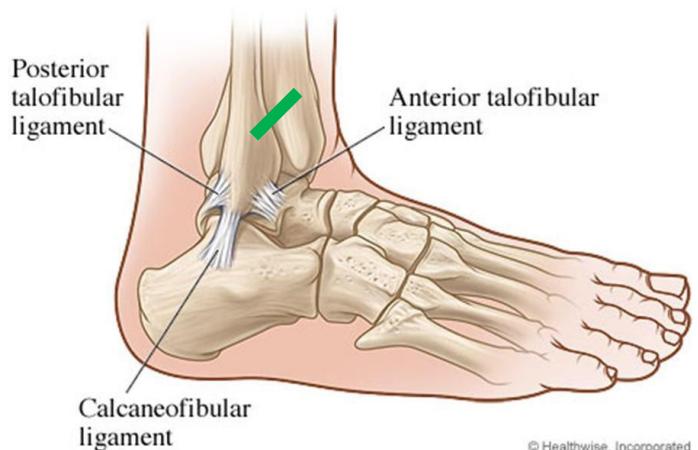
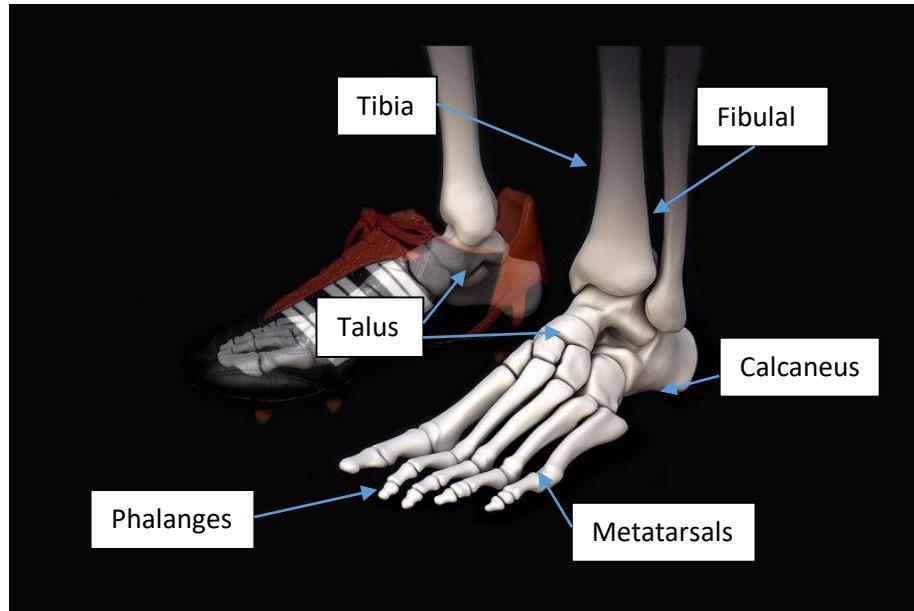


Lecture 2 – Musculoskeletal Modelling in Physical Rehabilitation

BONE ANATOMY OF THE ANKLE

- Shank, above the feet
 - o Long and thick: tibia
 - o Long and thin: fibula
- Views of the toes (phalanges) → most distal to the body:
 - o Medial: inside out (middle)
 - o Lateral: Outside in (side)
 - o Anterior: Front (Face on)
- Talus connects shank and foot together(bump on top of the foot)
- Joints
 - o True ankle joint is joint between talus and shank
 - If feet bends to ground: plantarflexion
 - If feet bends to sky: dorsiflexion
 - o Subtalar joint is joint below talus
 - If right side of foot goes inwards: inversion
 - If right side of foot goes outwards: eversion
- Muscles
 - o Moments → turning effect of force ($M = r \times F$)
 - o Plantarflexors
 - Over-branching name for triceps
 - Gastrocnemius cross both joints
 - Solems, when pushed up, causes calves to bend towards foot
 - o Dorsiflexors pushes up on the calves causing it to be pushed back
 - o Inverters rolls your ankle to either side
 - o Evertors rolls your ankle outwards
 - o Muscles that cause eversion that counteract inversion are called the peroneus muscle
- Ligaments
 - o Connect bone to bone
 - o Important for joint stability
 - o Important ligaments that contribute to injuries:
 - Anterior talofibular
 - Calcaneofibular
 - Posterior Talofibular
 - Anterior Tibiofibular (not focused for ankle injury) [green]



ANKLE INJURIES

Structure	Injury
Bone	Fracture, bruise
Ligament	Sprain
Muscle	Strain
Tendon	Tendinopathy
Cartilage	Tear

- Ankle Sprains → anterior talofibular ligament

- o Grade 1: Stretchy, small tears
- o Grade 2: Large, but incomplete tear
- o Grade 3: Complete tear

- Ankle sprains risk factor

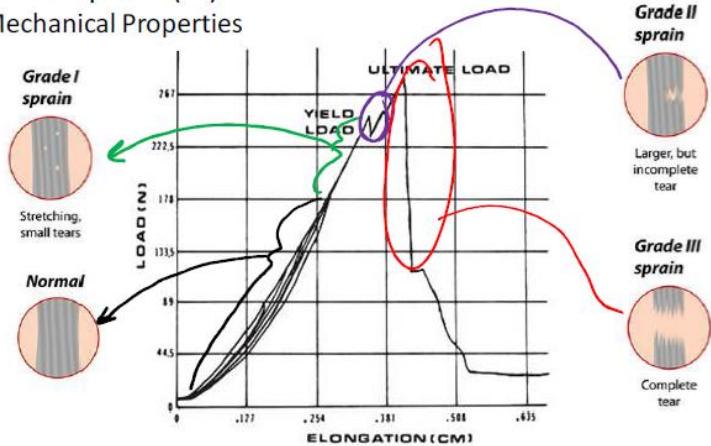
- o Previous or existing ankle injury (biggest factor)
- o Lack of strength, stability, flexibility in the ankle
- o Poor balance
- o Sudden acceleration and deceleration in direction
- o Increasing age

- Prevention of ankle sprains

- o Balance training
- o Ankle strengthening
- o Flexibility
- o Adequate preparation
- o Taping and bracing

Ankle Sprain (III)

Mechanical Properties



- Types of ankle braces

- o Compression
- o Rigid
- o Semi-rigid
 - Hinged
 - Laced

- Design requirements for ankle braces

- o Engineering
- o Functional
- o Aesthetic

Ankle Braces (I)

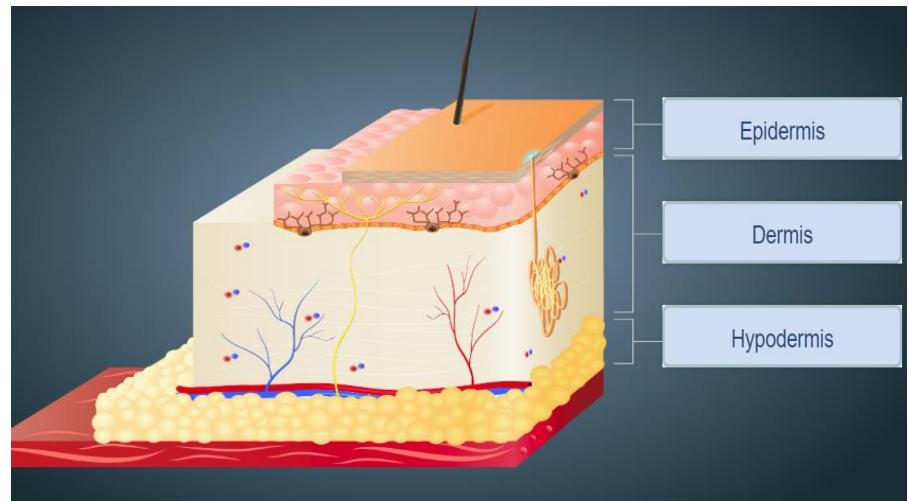
Types



Lecture 3 – Wound Healing

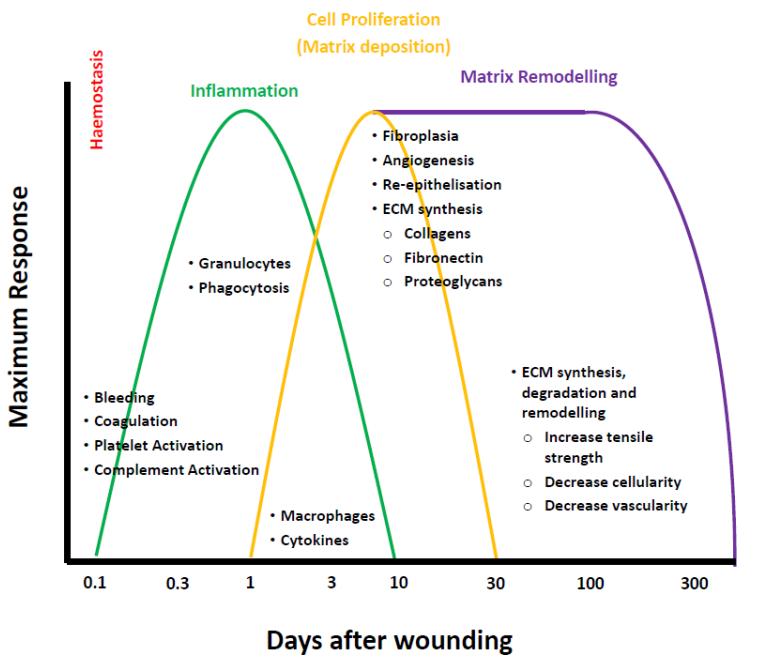
SKIN ANATOMY

- Epidermis (outermost layer of skin)
 - o Rich in tough protein called keratin, and containing two main types of cells:
 - Keratinocytes, barrier against environmental damage
 - Melanocytes, produces a pigment, melanin, responsible for skin color and protection of UV radiation
 - o Forms waterproof barrier between body and external environment
 - Resists friction
 - Resists microbial invasion
 - Prevents water loss from body
 - o Doesn't carry blood vessels, but receives nourishment from capillaries in dermis
 - o As cells of the outer surface of epidermis are shed, cells from the stratum basale (bottom layer of epidermis) divide and replenish the epidermis
- Dermis (beneath the epidermis)
 - o Contains all blood vessels and most nerve tissue from skin
 - o Responsible for:
 - Elasticity and strength of skin
 - supplier of nutrients for epidermis
 - Important for thermoregulation, regulate internal body temperature
 - o Contains two fibres:
 - Collagen fibres, provides skin with tensile strength and resistance to stretching forces
 - Elastic fibres provide its recoil properties
 - o Composed of numerous cell types:
 - Fibroblasts
 - Immune cells, eg. Macrophages
 - Adipocytes, cells that store energy as fat
 - o Divide into two sub-layers:
 - Papillary region composed of areolar connective tissue
 - Formed by protrusions of dermis into epidermis
 - Interior of protrusion supply epidermis with oxygen and nutrients
 - Contains tactile receptors, known as Meissner's Corpuscles (responsible for sensitivity to light touch)
 - Reticular region composed of dense connective tissue of thick bundles of collagen fibres
 - Contains: roots of hairs, sebaceous glands (secretes oil to lubricate skin and hair), sweat glands, receptors, nails, nerve endings and blood vessels
- Hypodermis (aka. Subcutaneous layer) lies below dermis
 - o Lies below dermis
 - o Connective tissue containing fat (adipose tissue: energy reserve, insulate body and cushion to protect underlying structures from trauma), blood vessels and sensory receptors
 - o Functions as a protective cushion and insulator
- Muscle layer lies below hypodermis

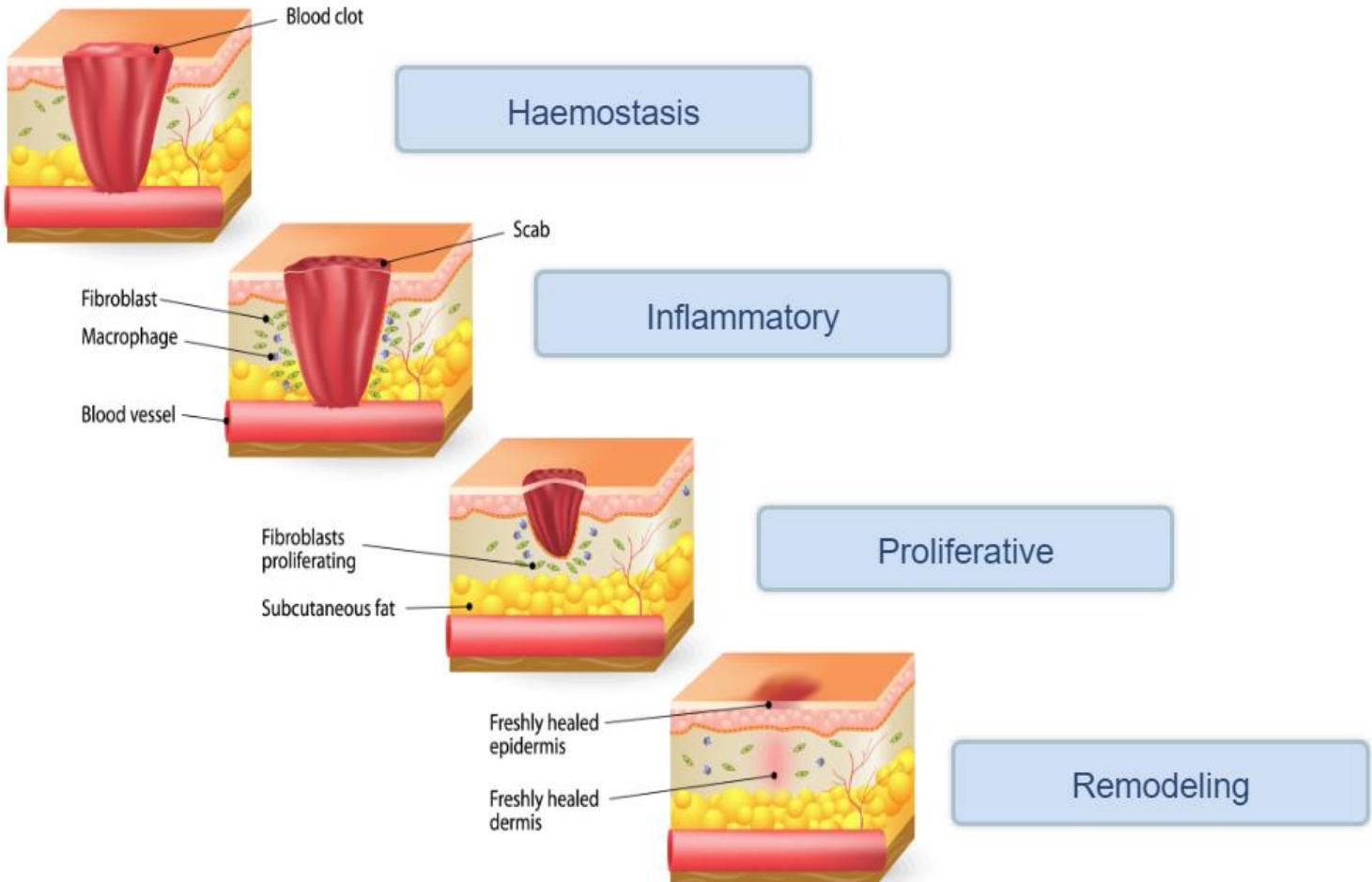


SKIN ANATOMY

- Haemostasis (causes wound to stop bleeding)
 - When cut → capillaries torn → bleeding
 - Injury to microvasculature (smallest systems of blood vessels in body) → constriction of blood vessels
 - Coagulation cascade activated, to stop bleeding
 - Blood clotting begins to prevent blood loss and protect against viruses or bacteria
 - Platelets bind directly to collagen (protein in muscles, bones, skin, blood vessels, etc.)
 - Von Willebrand Factor (WWF) by forming additional links between platelets and collagen (\uparrow strength)
 - Proteins formed:
 - Fibrin is an insoluble protein forms fibrous mesh and acts as a “glue” to bind platelets to each other to stop blood flow
 - Fibronectin is a glycoprotein (carbohydrate grouped protein) that anchors cells to collagen
 - Vitronectin is a glycoprotein that regulates coagulation cascade
 - Platelets release growth factors
 - Initiation of the wound healing
 - Attract and activate:
 - Fibroblasts is a biological cell combines the extracellular matrix and collagen to produce a structural framework for animal tissue to form (connective tissues)
 - Endothelial cells line inside of blood vessel to carry excess blood plasma around the body
 - Macrophages is a large white blood cell is to locate microscopic foreign bodies and eat them
- Inflammatory
 - Early Stage
 - Infiltration of inflammatory cells, due to the increased blood flow as tissue becomes reddened and swollen
 - Granulocytes is a white blood cell that has granules with enzymes to be released during infections
 - Polymorphonuclear leukocytes is a white blood cells released during infections, allergic reactions, and asthma
 - Phagocytosis is the removal of bacteria and foreign materials by phagocytes
 - Prevents infection
 - Late Stage
 - Monocytes (white blood cells) are attracted to wound area, such as macrophages
 - Growth factor and other effects on other cells release
 - Recruit fibroblasts, keratinocytes (an epidermal cell producing a fibrous protein), endothelial cells
 - Proteases, breaks down enzymes molecules as they go through tissue remodeling
- Cell Proliferation (Extra Cellular Matrix deposition)
 - Wound begins to heal
 - Migrations of fibroblasts → proliferation of fibroblasts
 - Start to produce ECM proteins (mostly found in the skin) which make up the dermis
 - Fibronectin
 - Collagen (enzyme protein) gives the skin the plumpness



- Proteoglycans
- Elastin gives the skin elasticity (comparing between teen to old)
- Collagen synthesis
 - Provides strength and structure to the dermis
- Angiogenesis is the formation of blood vessels from pre-existing ones
 - Big wound → blood vessels need to be replaced (within 200 microns) → Angiogenesis causes the blood to be replaced for nutrients to be applied, so wound can heal
 - Macrophages release angiogenic factors to switch on and produce new blood vessels
- Granulation tissue formation
 - Capillaries
 - Proliferating fibroblasts
 - Macrophages
 - Collagen
 - Glycoproteins
- Epithelialisation
 - Reformation of the epidermis
 - Migration of keratinocytes across the top of the dermis (wound)
- Matrix Remodelling (Regeneration)
 - Cells deposit matrix while remodeling the tissue, simultaneously
 - Occurs over prolonged time periods depending on the size of the injury
 - Breakdown and remodeling of ECM proteins, including collagen
 - As time passes, process slows down as wound is fully healed

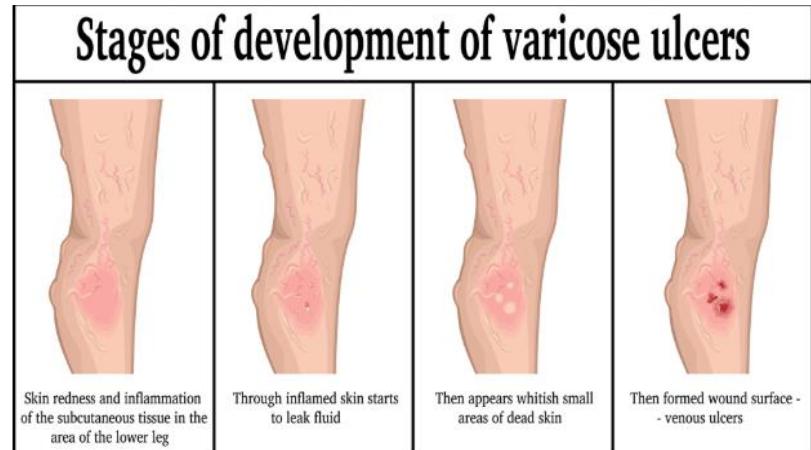


ABNORMAL WOUND HEALING

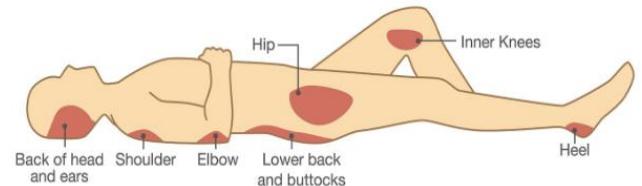
- Hypertrophic scar (Hyper → increasing)
 - o Confined to the border of original wound
 - o Reduce in size over time
 - o Use of collagen (from fibroblasts)
- Keloid scar
 - o Genetic issue, so when removed, it can come back
 - o Extend beyond the border of the wound (overgrowth of scar tissue)
 - o Will not reduce over time
 - o Thick collagen (excess collagen provided)

CHRONIC WOUND

- Venous Ulcer
 - o Non-functioning of venous valves, usually of the legs
 - insufficient blood flow
 - build-up of inflammatory cells
 - insufficient removal of waste produced by inflammatory cells
- Diabetic Ulcer
 - o Normally diabetes type 2 and seen on foot
 - o Pathologies that are associated with diabetic patients
 - Peripheral neuropathy – form of nerve damage, causing patient not to realize wound → delayed wound care
 - Peripheral arterial disease – similar to venous ulcer → limited blood flow causing build-up of inflammatory cells and waste
 - Infection – puts diabetic patients at a greater risk of wounds → worsen wounds and may require amputation
- Pressure Ulcer
 - o Commonly caused by restricted blood flow or absence of blood flow to region
 - Found in limited mobile patients and patients being in same position with increased pressure for a long period of time



Diabetic Foot



TREATMENT OF CHRONIC WOUNDS

- Problems
 - o Heterogeneous – all cases are different → different measures to be accounted for
 - o Underlying conditions – genetic symptoms/problems pre-existing before the problem
 - o Age – elderly
- Common courses of treatment
 - o Debridement is removing damaged tissues or foreign objects from wound
 - o Dressing
 - Sterile pad or compression
 - Promote healing and protection from further harm

PRESSURE SORES

- Compression/pressure bandages, negative pressure therapy
 - Compression bandages used to control fluids exerted from wound and reduce swelling in region
 - Pressure bandages compresses dead space and prevents blood clotting and blood plasma formation
 - Negative pressure therapy uses a vacuum dressing to promote and enhance healing in acute or chronic wounds, and 2nd or 3rd degree burns
- Skin grafts
 - Taking healthy skin to be transplanted to a new site on patient's body
 - Fixes original wound, while making another wound

Dressing type	Advantages	Disadvantages
Films (elastic sheets of polyurethane)	<ul style="list-style-type: none"> • Adherent • Transparent • Forms a bacterial barrier but is gas permeable 	<ul style="list-style-type: none"> • Fluid collection • Difficult to remove, which may disturb new keratinocytes
Foams (bilaminate sheets containing polyurethane and often silicone)	<ul style="list-style-type: none"> • Absorbent • Moist healing environment • Conforms to body contours 	<ul style="list-style-type: none"> • May require secondary dressing to place • Can adhere to wound if exudate dries
Hydrogels (96% water, cross-linked hydrophilic polymer)	<ul style="list-style-type: none"> • Comfortable • Absorbent • Promotes autolytic debridement 	<ul style="list-style-type: none"> • Nonadherent • Maceration of skin around wound
Hydrocolloids (carboxymethylcellulose in adhesive base)	<ul style="list-style-type: none"> • Improved healing • Easy to use • Waterproof • Promote granulation tissue 	<ul style="list-style-type: none"> • Unpleasant odor • Yellow brown, gel-like fluid drainage • May overstimulate granulation • Difficulty to use in cavities
Alginates (natural polysaccharides from kelp and algae)	<ul style="list-style-type: none"> • Absorbent • Useful in sinuses • Hemostatic properties 	<ul style="list-style-type: none"> • Not useful for dry wounds • May require frequent dressing change if lots of exudate

Lecture 4 – Image Processing for Physiological Measurement

IMAGE PROCESSING

- Human vision → easily biased, different perceptions
- Automated image analysis → unbiased, extract info from image data and tests hypothesis

IMAGE VS DIGITAL

- Image: 2D with x and y coordinates plane
 - Amplitude (f) is intensity at coordinate
 - Values varied over infinite space
- Digital: Same as image
 - Except values are finite → pixels, have particular position and f value
 - Restrictive space

- Pixel location of 2D function: $f(x,y,) = z \rightarrow f(\text{row}, \text{column}) = \text{pixel intensity value}$

COLOUR VS GRayscale

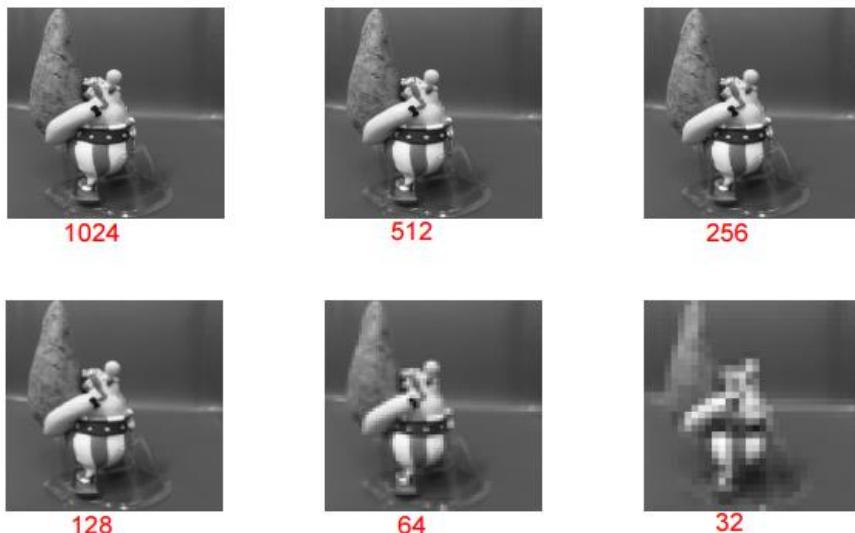
- Comes from pixels in digital image
- Colour
 - 3 channels → RGB (Red, Green, Blue) colour intensities
- Greyscale
 - 1 channel → range from black to white
 - Intensity stored as 8-bit binary no. (0-255)
 - Eg. 0 → black → grey → white
 - Saturation of grey depends on which side it leans towards
 - Intensity of colour = avg. of values in selected space

SAMPLING

- Changing the picture resolution
 - Lowering resolution → increases blur between pixels → unclear image

MATLAB coding

- `imresize(variable given to image, [Original pixel size]/sampling factor)`
 - Eg. `imC = imread('pepper.png')` [loading picture]
 - `imG = rgb2gray(imC)` [convert RGB → grey-scale]
 - `im1 = imreszie(imG,[1024 1024])` [initial pixel size of image]
 - `Im2 = imresize(im1,[1024 1024])/2` [sampling to sampling factor]



QUANTISATION

- Convert light intensity and frequency into digital color values
 - Smudges light colours into shades of black
- MATLAB coding
 - `[new image name,map# quantising factor] = gray2ind(converted image, quantising factor)`
 - `imC = imread('pepper.png')`
 - `imG = rgb2gray(imC)`
 - `[im2,map2] = gray2ind(imG,2^7)`

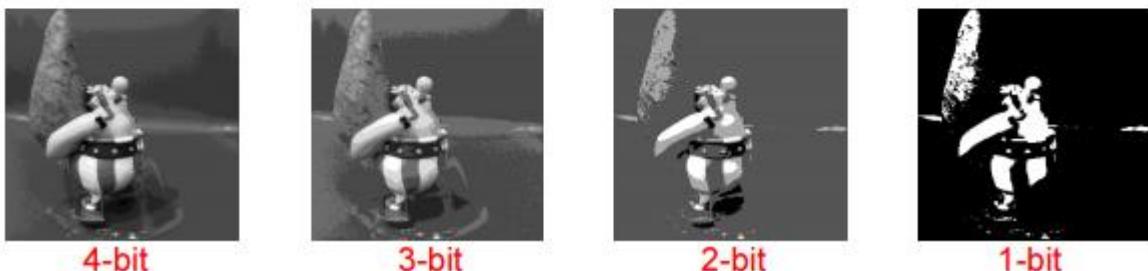


8-bit

7-bit

6-bit

5-bit



4-bit

3-bit

2-bit

1-bit

RESIZING IMAGE

- Zoom-in → poor resolution → blurred image
- Assign value to pixel in output image → value = location → resized image

2D INTERPOLATION METHODS

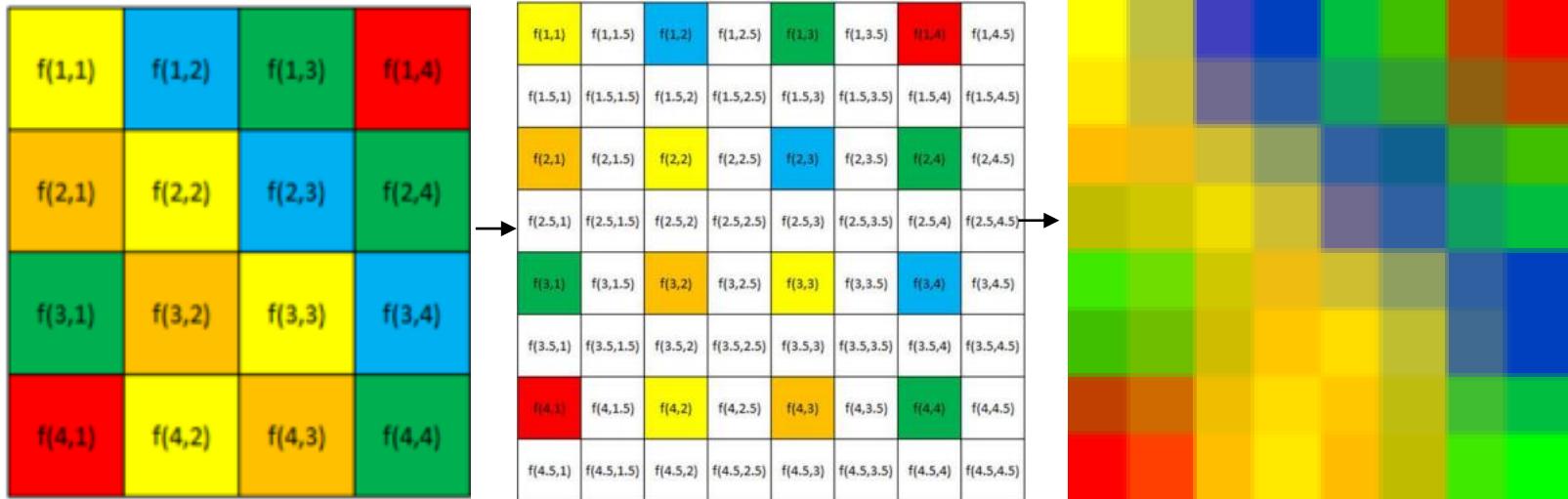
- Using known values/points, to estimate values of unknown points → alter picture format
- Nearest neighbor interpolation
 - o Nearby values in space around given point are similar to the given point
 - o Squares reduce down, to determine, square location
 - o $f(x,y) = f(\text{floor}(x), \text{floor}(y))$
 - o In pic, space close around black dot → coloured same
 - o Final picture blurred → when zoomed → squares are formed → proof of method

$f(1,1)$	$f(1,2)$	$f(1,3)$	$f(1,4)$
$f(2,1)$	$f(2,2)$	$f(2,3)$	$f(2,4)$
$f(3,1)$	$f(3,2)$	$f(3,3)$	$f(3,4)$
$f(4,1)$	$f(4,2)$	$f(4,3)$	$f(4,4)$

$f(1,1)$	$f(1,1.5)$	$f(1,2)$	$f(1,2.5)$	$f(1,3)$	$f(1,3.5)$	$f(1,4)$	$f(1,4.5)$
$f(1.5,1)$	$f(1.5,1.5)$	$f(1.5,2)$	$f(1.5,2.5)$	$f(1.5,3)$	$f(1.5,3.5)$	$f(1.5,4)$	$f(1.5,4.5)$
$f(2,1)$	$f(2,1.5)$	$f(2,2)$	$f(2,2.5)$	$f(2,3)$	$f(2,3.5)$	$f(2,4)$	$f(2,4.5)$
$f(2.5,1)$	$f(2.5,1.5)$	$f(2.5,2)$	$f(2.5,2.5)$	$f(2.5,3)$	$f(2.5,3.5)$	$f(2.5,4)$	$f(2.5,4.5)$
$f(3,1)$	$f(3,1.5)$	$f(3,2)$	$f(3,2.5)$	$f(3,3)$	$f(3,3.5)$	$f(3,4)$	$f(3,4.5)$
$f(3.5,1)$	$f(3.5,1.5)$	$f(3.5,2)$	$f(3.5,2.5)$	$f(3.5,3)$	$f(3.5,3.5)$	$f(3.5,4)$	$f(3.5,4.5)$
$f(4,1)$	$f(4,1.5)$	$f(4,2)$	$f(4,2.5)$	$f(4,3)$	$f(4,3.5)$	$f(4,4)$	$f(4,4.5)$
$f(4.5,1)$	$f(4.5,1.5)$	$f(4.5,2)$	$f(4.5,2.5)$	$f(4.5,3)$	$f(4.5,3.5)$	$f(4.5,4)$	$f(4.5,4.5)$

$f(1,1)$	$f(1,1)$	$f(1,2)$	$f(1,2)$	$f(1,3)$	$f(1,3)$	$f(1,4)$	$f(1,4)$
$f(1,1)$	$f(1,1)$	$f(1,2)$	$f(1,2)$	$f(1,3)$	$f(1,3)$	$f(1,4)$	$f(1,4)$
$f(2,1)$	$f(2,1)$	$f(2,2)$	$f(2,2)$	$f(2,3)$	$f(2,3)$	$f(2,4)$	$f(2,4)$
$f(2,1)$	$f(2,1)$	$f(2,2)$	$f(2,2)$	$f(2,3)$	$f(2,3)$	$f(2,4)$	$f(2,4)$
$f(3,1)$	$f(3,1)$	$f(3,2)$	$f(3,2)$	$f(3,3)$	$f(3,3)$	$f(3,4)$	$f(3,4)$
$f(3,1)$	$f(3,1)$	$f(3,2)$	$f(3,2)$	$f(3,3)$	$f(3,3)$	$f(3,4)$	$f(3,4)$
$f(4,1)$	$f(4,1)$	$f(4,2)$	$f(4,2)$	$f(4,3)$	$f(4,3)$	$f(4,4)$	$f(4,4)$
$f(4,1)$	$f(4,1)$	$f(4,2)$	$f(4,2)$	$f(4,3)$	$f(4,3)$	$f(4,4)$	$f(4,4)$

- Bilinear interpolation
 - o Averages values around initial value → converts to new colours
 - Average out between two fixed distinct points → mixture of the two colours → causes blur between the two points of contact



- Bicubic interpolation
 - o Average out between 16 nearest pixel values → mixture of all 16 pixel values → causes blue between points of contact
 - o Clearer than bilinear interpolation → Average more pixel values = clear image

Nearest Neighbor

128 → 1024



Bilinear



Bicubic



64 → 1024

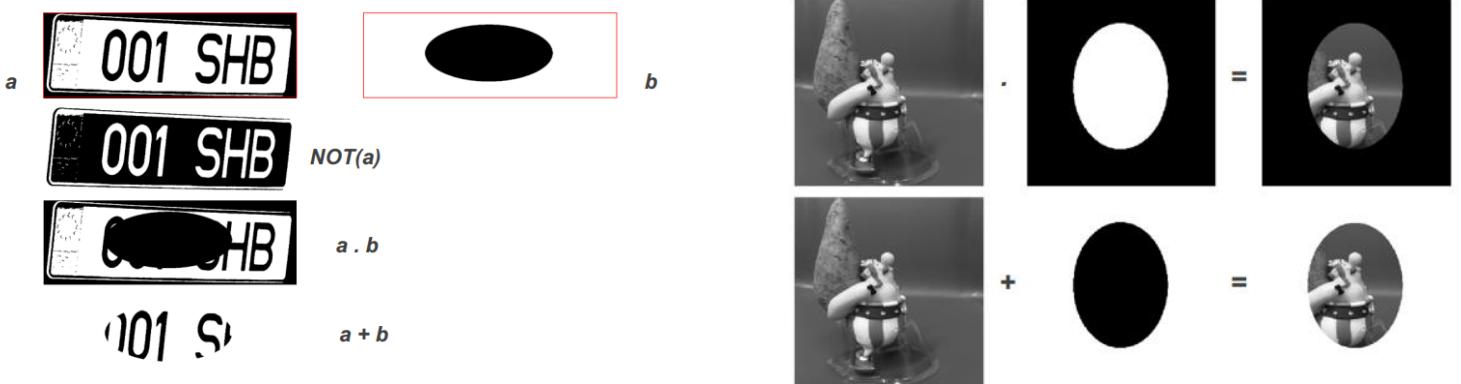


LOGARITHMIC TRANSFORMATION

- $Q(i,j) = c * \log(1 + |P(i,j)|)$
 - o $1 + \rightarrow \log(0)$ is undefined
 - o c is constant scaling factor for, $Q(i,j) = 255$ if $|P(i,j)| = \text{max input value}$
 - o \log has any base → can be defined by question
- Enhance low-intensity pixel values → BUT lose information on high pixel values eg. pictures with a lot of detail
- Eg. Spreads dark face pixels over wider range, while higher values are compressed → greater detail in unclear spots of original

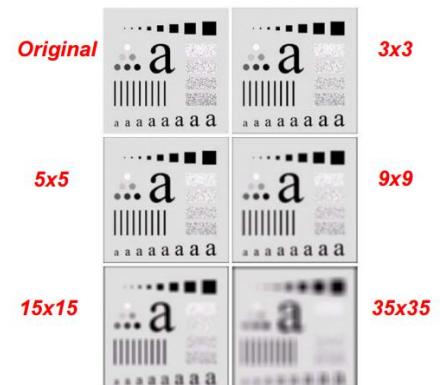
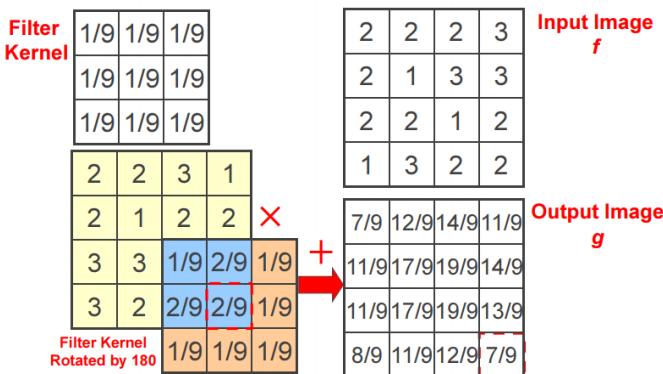


LOGIC OPERATIONS



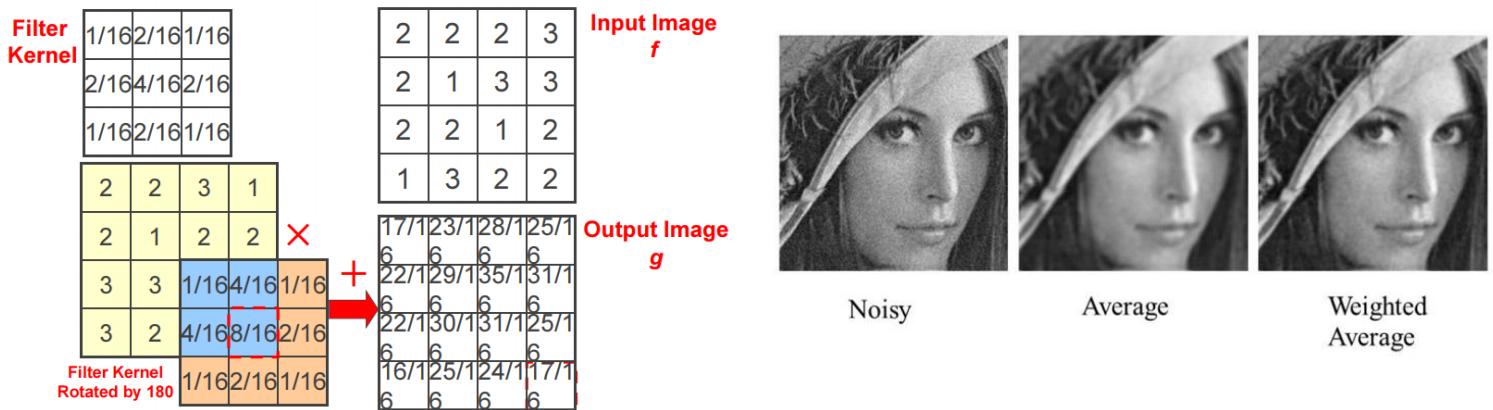
FILTERING

- Remove noise (dots, speckles, stains) → clearer photo
- Uses
 - o Noise removal: remove speckles/dots in image
 - Either mean or median values of neighboring pixels
 - = low-pass filtering
 - But may have blur edges → more advanced techniques needed (eg. adaptive or edge preserving)
 - o Mean/Average filter
 - o Replace pixel by average of pixels surrounding specific pixel
 - o Average out sharp transitions → smooth image
 - More pixels taken for average → remove more noise → BUT blur detail
 - o Most have data as fractions
 - o Filter kernel: the degree of filter used
 - o MATLAB coding
 - `I = imread('coin.png')` [read grayscale image]
 - `H = fspecial('average', [3,3])` [create pre-defined 2-D filter]
 - `J = imfilter(I,H)` [apply filter]
 - OR `I = imread('coin.png')` [read grayscale image]
 - `K = ones(3,3) / 9` [define filter kernel]
 - `J = conv2(I,K,'same')` [perform convolution, but keep sizing of I]



- Weighted Average filter
 - o Closer-by pixels have higher weighting → far-away pixels have lower weighting
 - o All data values are positive
 - o Keeps low-frequency, BUT suppresses high frequency = low-pass filter
 - o Problems
 - Blur edges/details → unclear image

- Not effective against impulse noise (random high intensity pixel) → salt and pepper
- MATLAB coding
 - `I = imread('coins.png')` [read grayscale image]
 - `Figure; imshow(I)` [display image]
 - `K = [1,2,1;2,4,2;;1,2,1] / 16` [define filter kernel]
 - `J = conv2(I,k,'same')` [perform convolution, keeping size of I]
 - `Figure; imshow(uint8(j))` [display image]



- Median filter
- Takes median value of surrounding pixels around specific pixel
 - Sort pixels in increasing order → take middle one
- Improves image severely corrupted by defective pixels
- MATLAB coding
 - `I = imread('coins.png')` [read grayscale image]
 - `I = imnoise(I,'salt & pepper',0.02)` [add salt and pepper noise to image]
 - `Figure; imshow(I)` [display image]
 - `J = medfilt2(I,[3,3])` [perform convolution, while keeping size of I]
 - `Figure; imshow(J)` [display image]

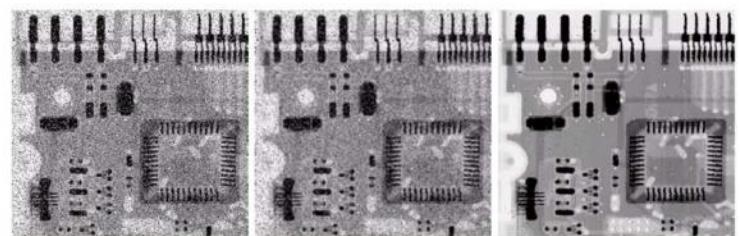


IMAGE SHARPENING

- Enhanced image = original image + scaled version of line structures and edges in image → greater detail on image
 - Line structures and edges obtained = high pass filter

- Data values: weighted average operation, but some are negative and $\sum=1$
- High-pass filter
 - Difference of current and average of nearby pixels (weighted averaging)
 - Used for edge detection
 - Example on right →
- MATLAB coding
 - `I = imread('coins.png')` [read grayscale image]
 - `Figure; imshow(I)` [display image]
 - `K = [0 -1 0; -1 4 -1; 0 -1 0]` [define filter kernel]
 - `J = conv2 (I,K,'same')` [perform convolution, keeping size of I]
 - `Figure; imshow(unit8(J));` [display image]

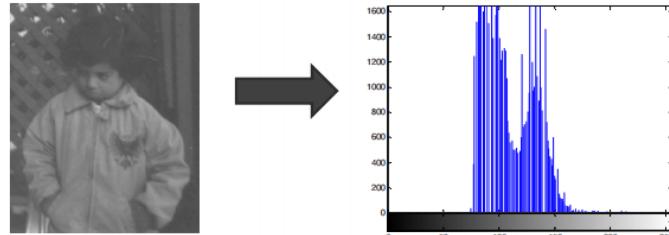
$$\begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix}$$

NB: Sum of elements is 0

$$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

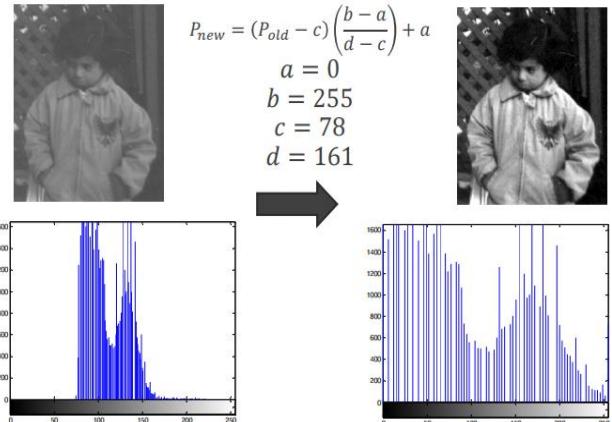
IMAGE HISTOGRAM

- Graphical representation of pixel intensity distribution → plot number of pixels for each pixel intensity
- Scanned → running count of no. of pixels at each intensity value



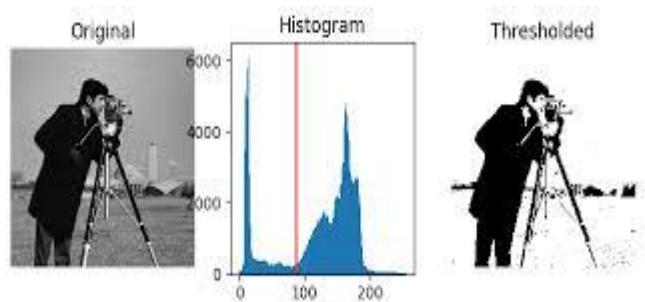
CONTRAST STRETCHING

- Improve contrast in image by expanding range of intensity values
 - Important to specific upper and lower pixel value limit
- MATLAB coding
 - `I = imread('pout.tif')` [read image]
 - `Figure; imshow (I)` [display image]
 - `Figure; imhist(I)` [display histogram]
 - `[minI,maxI] = stretchlim(I)` [find max. & min. intensity value]
 - `J = imadjust(I,[minI,maxI],[],[])` [perform contrast stretching]
 - `Figure; imshow(J)` [display image]
 - `Figure;imhist(J)` [display histogram]



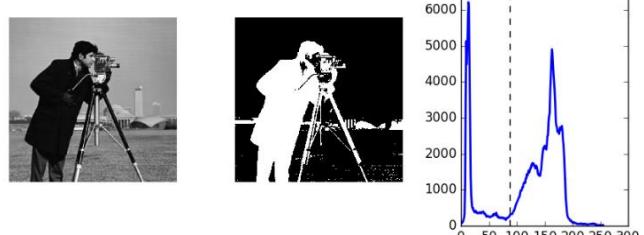
HISTOGRAM EQUALISATION

- Pixel distributed evenly over whole intensity range → flat histogram



THRESHOLDING

- Bi-modal: pixel intensities are clustered around two well-separated values
- Threshold between two peaks → no peaks = threshold not determined by uneven distribution
- Histogram of image → determine two max peaks → determine threshold level via average peak



OTSU THRESHOLDING

- Chooses threshold with minimum difference between white and black pixels
- MATLAB CODING

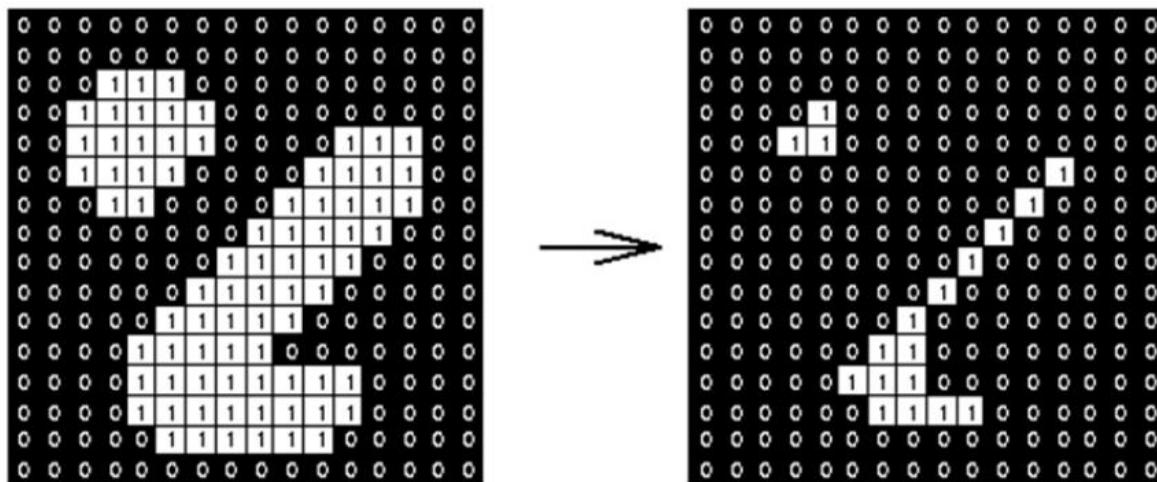
- Read grayscale image → level = graythresh(I) [determine otsu threshold] → convert grayscale image to binary image → display image

MORPHOLOGICAL OPERATIONS

- Binary regions by thresholding → distorted by noise and texture → morphological operations remove imperfections
- Non-linear operations → creates a new binary image → pixels have non-zero values only if test is successful
- Probe image with a template called structuring element
 - Structuring element = small matrix of pixels
 - Dimensions depend on whatever is chosen
 - Pattern of ones and zeros to specific shape
 - Marked with 0 → intersects of hits structuring element, marked with 1 → structuring element fits
- Each structuring element placed on each value of the original image, to produce output image

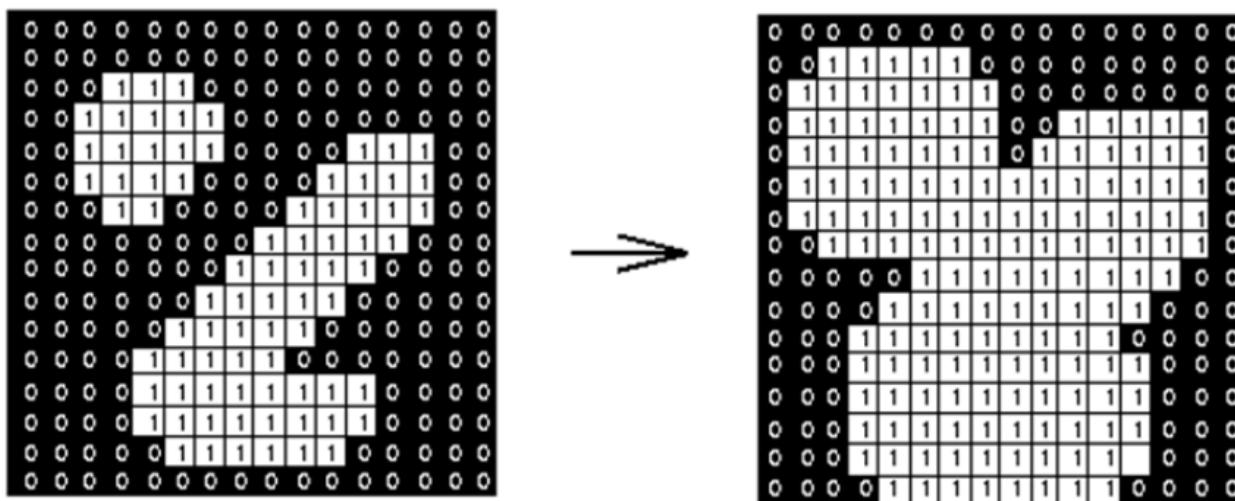
MORPHOLOGICAL EROSION

- Tests whether structuring element fits
- Eg. Used to separate touching objects to count them all up



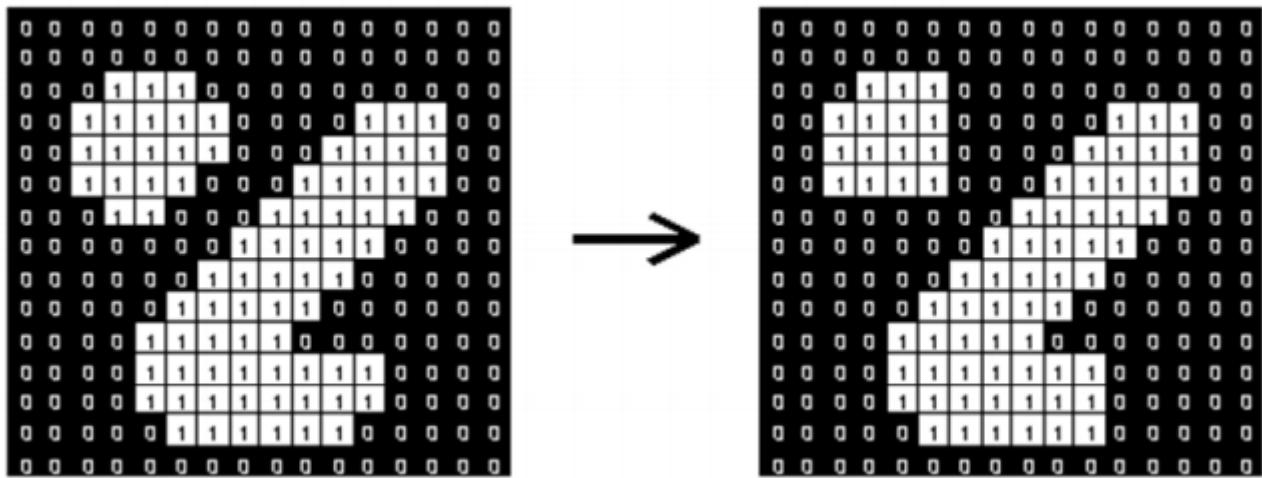
MORPHOLOGICAL DILATION

- Tests whether structuring element 'hits' → filled space with zero



MORPHOLOGICAL OPENING

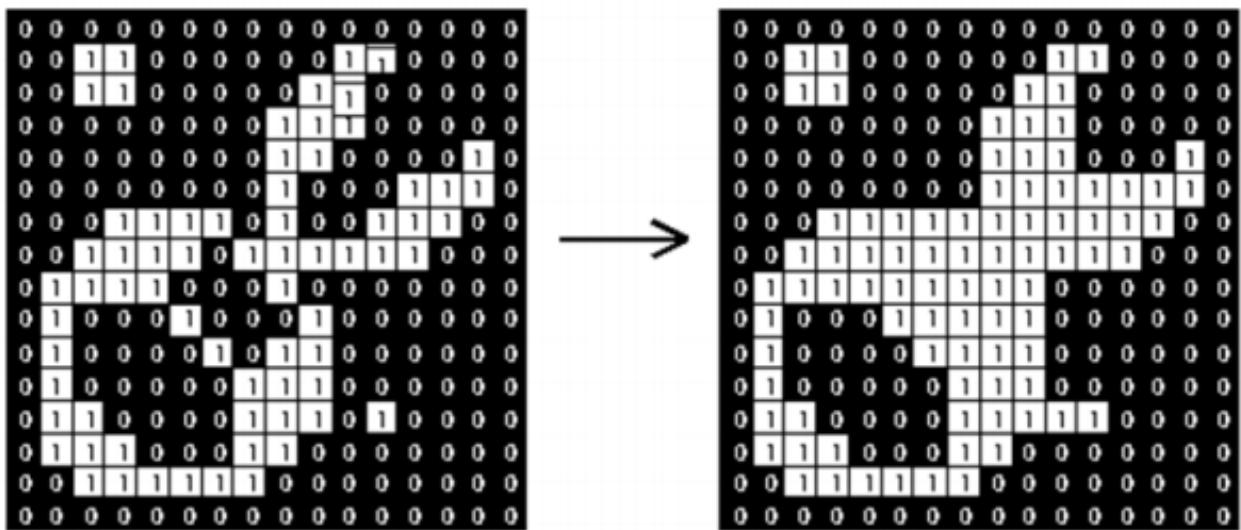
- Morphological erosion followed by dilation with same structuring element



- Can separate out circle from lines, or, horizontal with vertical lines

MORPHOLOGICAL CLOSING

- Morphological dilation followed by erosion with the same structuring element



MATLAB FUNCTIONS

- `imread()`: reads image → ensure to have file type at end, eg. 'office_2.jpg'
- `Figure();`: open into new window
- `imshow()`: displays image
- `imcomplement()`: invert colour → white turns black, while black turns white
- `imssubtract()`: difference of intensity of two images → new output photo
- `imhist()`: display a histogram
- `histeq()`: perform histogram equalization
- `im2bw(image variable, threshold value (between 0-1))`: convert grayscale image to binary image
- `regionprops(image variable, 'properties')`: returns set of properties from components of binary image

Lecture 5 – Ethics in Engineering

MEANING

- Set of standards of human behavior
- Code of professional conduct
- Values of right and wrong, or set of moral principles

TYPE OF ETHICS

- Professional Ethics
 - Honest and impartial
 - Not publishing false reports
- Patient Ethics
 - Confidentiality
 - Full disclosure of patient details
- Natural & Human Ethics
 - Not interfering with nature and life
 - Not pulling the “playing God” act

CODES OF BIOMEDICAL ENGINEERING ETHICS

- Hippocratic oath – medical ethics
- ABET & IEEE codes – engineering ethics
- Biomedical engineers – indirect practitioners (works closely with clinical practitioners)
- Associations with these codes ^:
 - Accreditation Board of Engineering Technology (ABET – USA)
 - Engineers Australia
 - IEEE (Institute of Electrical and Electronics Engineers)
 - Biomedical Engineering Society (BMES)
 - American Society of Mechanical Engineers (ASME)

CONSEQUENCE OF BREAKING CODE OF ETHICS

- Despite not being the law; legal prosecution focused on the outcomes of such behavior can happen
 - Eg. Personal injury or class action lawsuits
- Lose reputation, credibility, employment and research funding (such as; peers, elite organizations, government and funding agencies)

Lecture 6 – Bionic Hearts

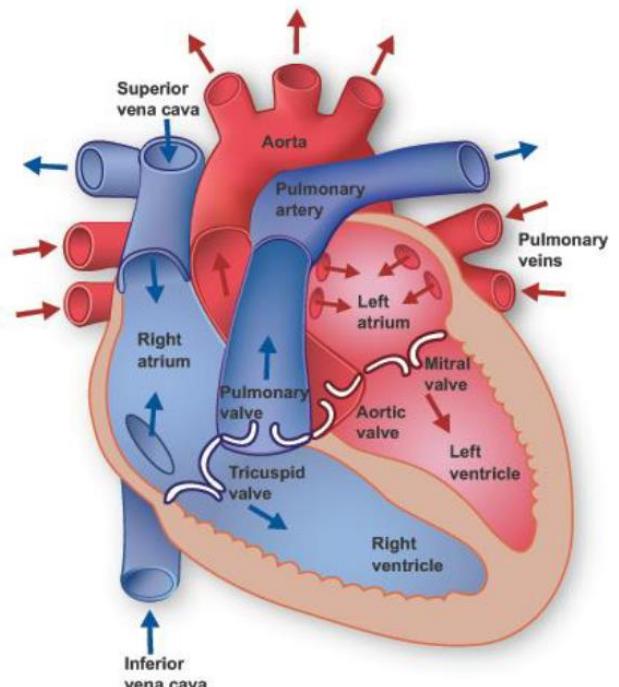
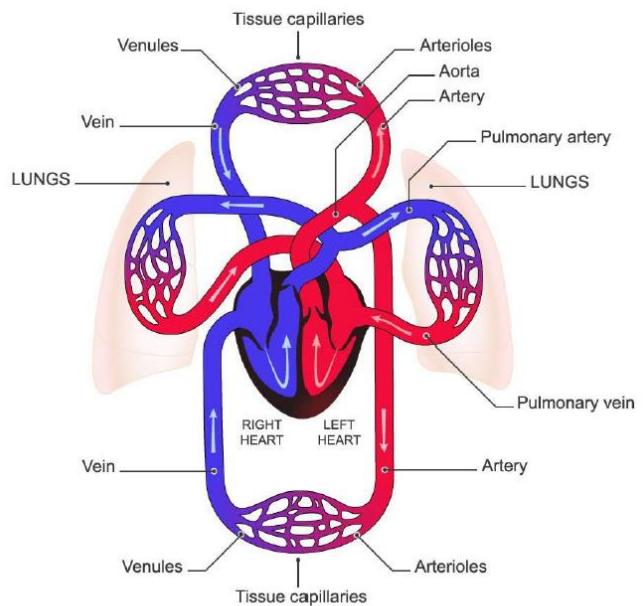
PART 1 – CARDIOVASCULAR PHYSIOLOGY (NOT EXAMINABLE)

PURPOSE

- Transports oxygen to body cells and takes away carbon dioxide (mainly)
- Regulates body temperature and water content of cells
- Carries white blood cells and antibodies to protect against disease

CIRCULATION

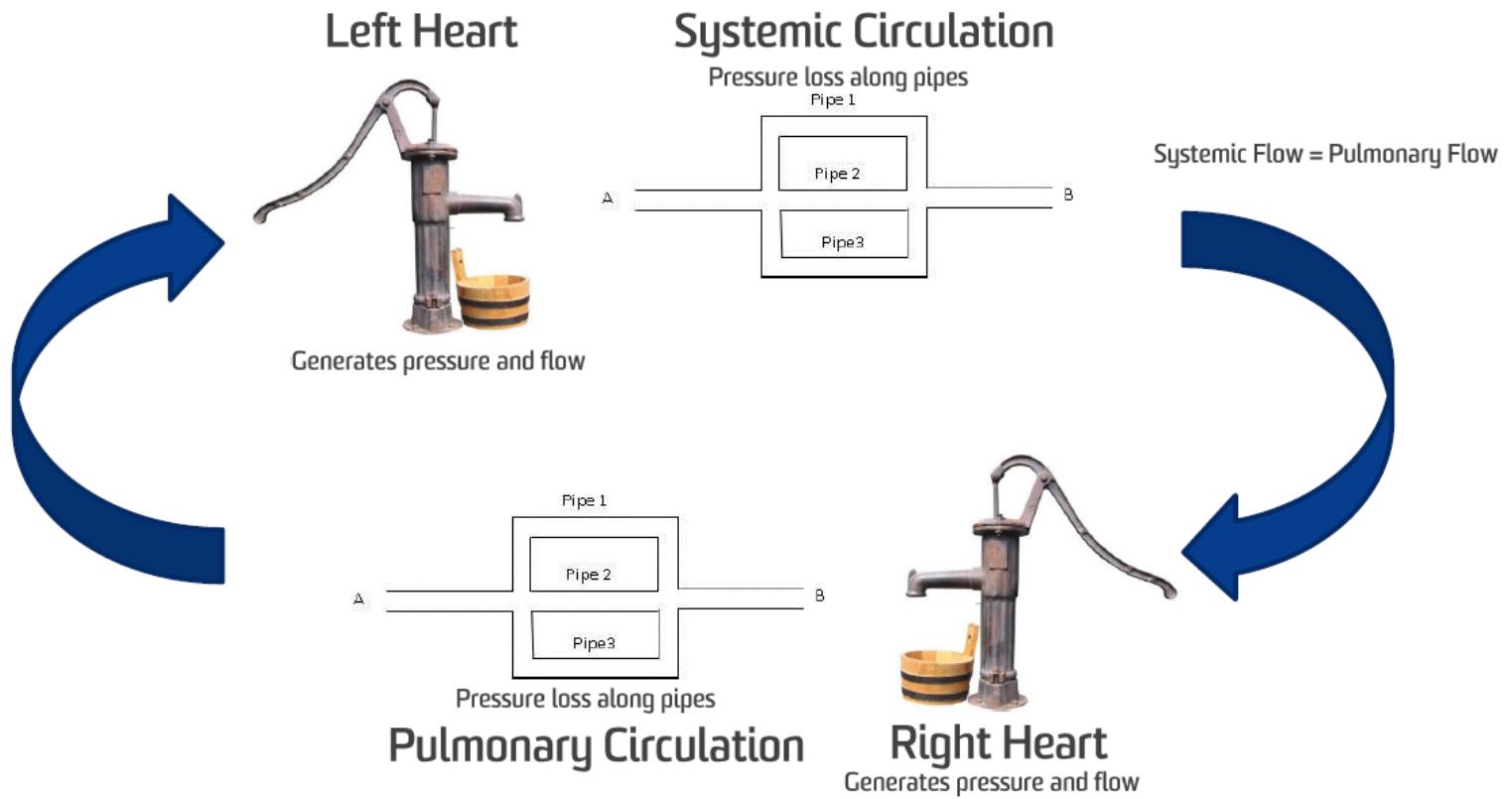
- Left Heart has oxygen-rich blood
 - Pumps blood into aorta (largest vessel) out of left ventricle
 - Blood → Collarbones → limbs + legs
 - Blood → aortic arch → brain and body (eg. Kidney and guts)
- When blood moves, blood vessels get smaller
 - Largest = aorta
 - Smallest = tissue capillaries
 - Oxygen leaves blood for tissues, while CO₂ leaves cells into blood
- Blood in vena cava → Right heart
 - No oxygen in right heart, since all gone to cells
 - REPEAT: Pumps deoxygenated blood to lungs to pick up oxygen and drop CO₂, and returns to left heart
- Ventricles = main driving force
 - Left Ventricle bigger than right ventricle
 - 5-10x more energy, ∵ more pressure
 - More skin on outside, so muscles squish more blood out
- Atria/atrium
 - Collects blood before it goes into ventricles
 - Right atrium receives deoxygenated blood from veins
 - Left atrium oxygenates blood from pulmonary veins
- Heart has 4 valves
 - Blood is one-directional
 - Heart is pulsatile (relaxes and contracts), to continue flowing blood
- Question: What happens to pressure and flow in systemic circulation when the left ventricle fails? (see pic)
 - Flow and pressure goes down
 - Less force, less energy
 - Min flow rate/pressure to allow blood to into tissue
- Question: What happens to pressure and flow in pulmonary circulation when the left ventricle fails? (see pic)
 - Pressure rises as right heart pumps strongly
 - Accumulation of blood, since left heart does not function



- Question: Do you think that the body compensates for LV heart failure? Yes/No?
 - Yes
 - Needs to maintain cardiac output (amount of blood pumped/min) and RAP (blood pressure of right atrium)
 - Heart beats faster to maintain → attempts to gain oxygen in heart → increase muscle mass (due to overwork) → heart enlargement

HEART DISEASE

- Causes: dysfunctional heart valves, virus, birth defects or coronary artery disease (damage in heart's blood vessel)
- Heart has to be alive when taken out (eg. On life-support) ∴ Not-enough donors



PART 2 – MECHANICAL THERAPY (EXAMINABLE)

1st Gen.



2nd Gen.



3rd Gen.



VENTRICULAR ASSIST DEVICES (VADs) supports failing ventricles

- 1st Gen
 - Tried to mimic heart
 - Pneumatic (air or pressurized gas)/electric
 - Sits outside of body (usually)
 - Can see blood going in and out
 - Connected to large air compressor ∴ lack mobility → poor quality of life
 - Very uncomfortable
 - Prone to infection, especially around tube gap into body
 - Potential to create blood clots in valves
 - Provide short term support
 - Aged out in developed countries because of poor functionality

- 2nd Gen

- Adapted a more continuous air flow; centrifugal or axial
- Longer support (approx. 8 years) compared to 12-24 months
- Steady decrease of survival over prolonged time
- Small – sized → more mobility
- Electronically driven
 - No pump = no air compressors
 - Less power requirements



Centrifugal

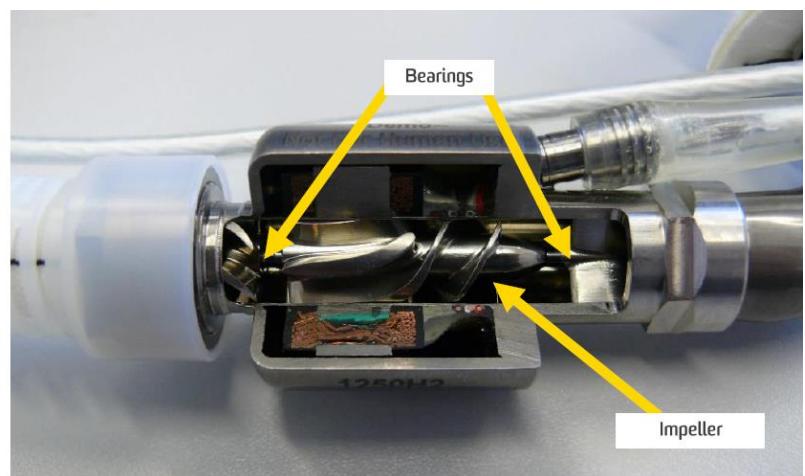
2nd Gen.



Continuous flow

Axial

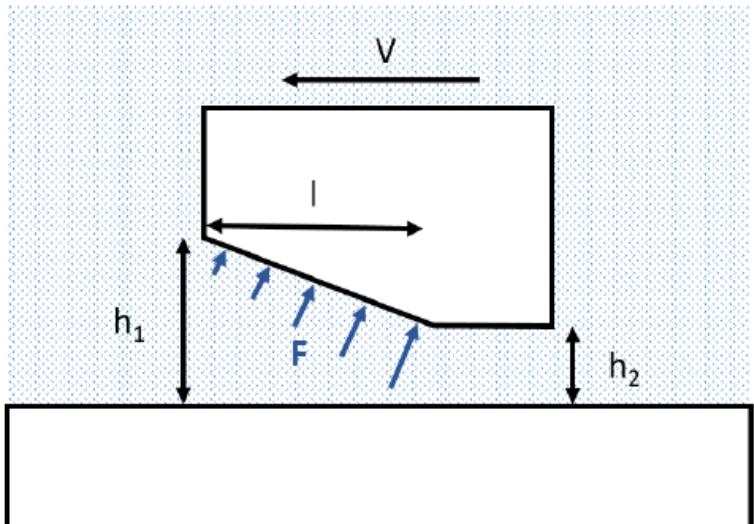
- Disadvantages:
 - Mechanical contact → formation of blood clots
 - Goes through impeller → breaks it → loses functionality
 - Size Growth → jams impeller → VAD breaks down
 - Goes through untouched → travels to patient's brain → death
 - Blood Damage
 - Infection
- DESIGN:
 - Impeller = spiral disk
 - sucks blood and pushes it back out with higher flow rate
 - Needs bearing to spin
 - Thrust Bearing
 - Stop impeller from moving
 - Point of contact with bearings
 - Very high shear stress
 - Blood cells caught and torn to shreds



- 3rd Gen

- Continuous flow: axial + centrifugal
- Completely implantable, with small cable exiting body
- No mechanical wear → impeller has no contact with any parts
- DESIGN:
 - **Hydrodynamic** Bearings

- Disk spins fast → little slope on bottom generates lift force → allows impeller disk to float above
- High-pressure fluid (blood) underneath rotor
- Rotor sits on top of blood
- Clearance (h = height between rotor/impeller and housing) needs to be large enough to prevent blood trauma
- Small Clearance (h) required to generate pressure
 - Too big, won't generate lift force
 - Blood is thick, so high shear rates can damage it
 - ∴ Clearance needs to be big enough to allow blood undamaged, but small enough to generate enough lift force to lift impeller off housing
- Changes in clearance requires change in speed or surface area
- Min start-up speed required to maintain lift force
 - Not fast enough = drags impeller along casing → damage blood cells

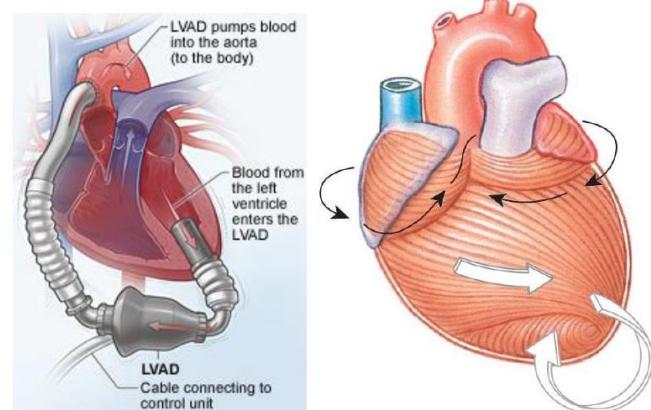


- **Electromagnetic** bearings

- Magnets on either side of the impeller suspends the impeller between them
- Can do large gaps → prevents blood cell damage
- Magnets are large and bulky
- More power than hydrodynamic
- Requires additional sensors for control over rotor position

VADs GENERAL COMPLICATIONS

- Bleeding is biggest
 - Patients often take anti-clotting meds
 - Greater risk of death if they get a cut/graze
- Infection
 - Potentially due to trauma at exit site
 - Patient's movement causes driveline (cable) to wiggle → damage suture, etc.
 - Easier for bacteria to enter
 - Require daily monitoring and dressing changes
 - Very difficult to treat
 - Driveline design and coating can cause VAD infection
 - Have tried transcutaneous energy transfer (wireless)
- Right Heart failure (see right)
 - Right ventricle needs to keep up with left side
 - LVAD support, more common
 - Can use two 3rd gen LVAD's, since Bivads have poorer survival rates
 - Cause respiratory failure
- Neurological dysfunction
 - Due to thrombus (clots) forming in ventricle or LVAD



- Important to optimize LVAD and ventricular flow dynamics
- Cannula design reduces neurologic complications from ~23% → ~4%
- Cardiac Arrhythmia
 - Irregular heartbeat
 - Cause reduced blood flow, right heart failure, thrombus
 - Caused by cannula-heart interference
 - Heart can be sucked onto cannula by negative pressure created by LVAD

TOTAL ARTIFICIAL HEARTS (TAH)

- Completely replaces the heart, ie. takes out heart and replaces completely
- Used if:
 - Native heart cannot support life
 - Ineligible for transplant (ie. Not enough heart donors)
- Large-sized; needs large patient
 - Some women and children ineligible
- Similar principle to 1st Gen VADs
 - Pulsatile pump (with valves) connected to huge air compressor
 - Same disadvantages as 1st Gen VADs, ie. size or lack mobility
- 2nd and 3rd Gen VADs
 - Whole heart taken out and replaced with turbines
 - No heartbeat → continue flow
 - Worked on animals
 - Worked on first impromptu patient → died soon after



Left ventricular assist
device (LVAD)



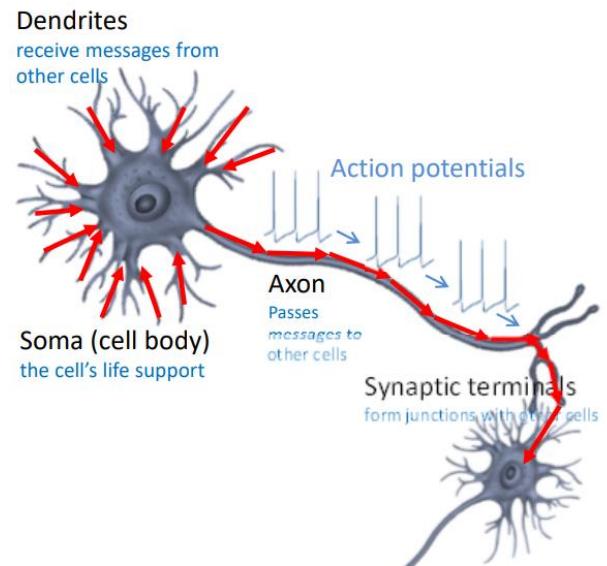
Total artificial heart
(TAH)

Lecture 7 – Excitable tissue, neural interfaces and bionic eyes

PART 1: BIONIC NEUROPHYSIOLOGY

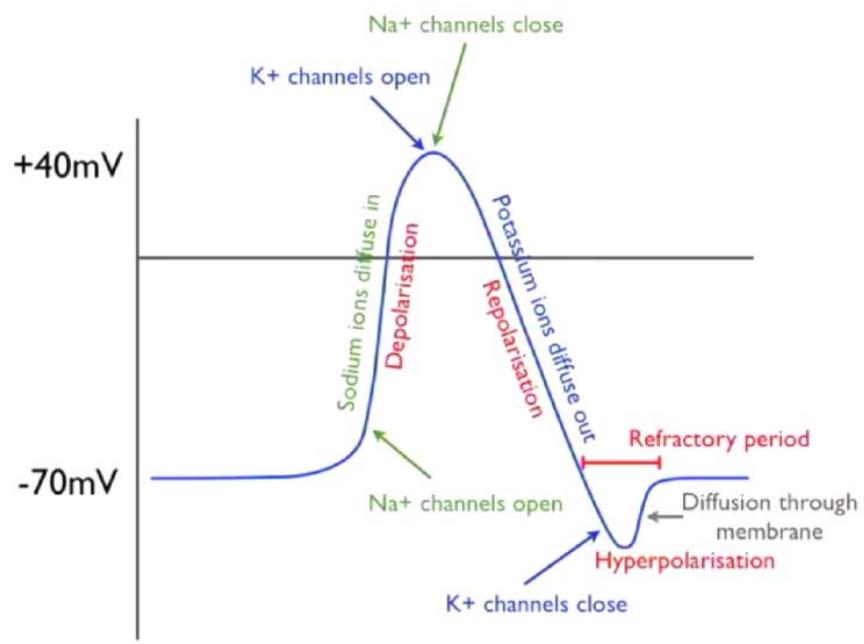
STRUCTURE OF A NEURON

- Dendrites
 - Reach out/add and summarize messages and signals from other cells
 - Dendritic arbor: used to collect/sense environment
- Messages from here are communicated to the SOMA
 - SOMA = cell body/machinery
- Travels to the formation of AXON
 - If there is enough activity, it creates an action potential
 - Action potential can propagate down axon to synapses where it communicates with other dendrites
 - The wrapping about the axon = myelin
 - Myelin sheath = fatty layer on cell exterior (ie. like wire insulation)
 - Allows AP to propagate faster with less energy
 - Some diseases can cause loss of myelin sheath, causing slow propagation of AP
 - Axon not fully insulated, or else AP won't propagate
 - Myelin sheath has gaps
 - Gaps = node of Ranvier
 - AP form and propagate between gaps

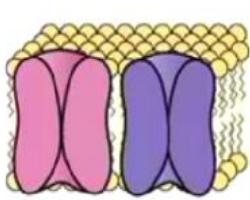


ACTION POTENTIAL (AP)

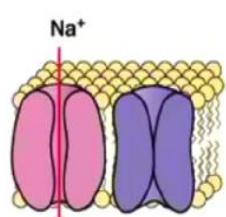
- Pulse-like wave that travels long excitable cell membranes
- Travels via axon
- All or none process (either: nothing happens, or all steps below occur, at about same mV values)
- Repetitive process, travelling along length of axon in node of Ranvier
- At rest, voltage in cell = -70V (resting potential)
 - Maintains this by pumping Na and K
- If chemical signals received by dendrites are sufficient to cause voltage to get to threshold point (ie. -55mv)
 - Sodium channel opens = depolarization
 - Voltage increases to max point (40V)
 - After this point, sodium channel deactivates and K⁺ channel opens
 - Cells polarize to negative membrane



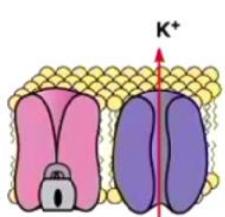
- Tends to overshoot → K channels remain open (while Na is inactive) → membrane potential becomes more negative → but overshoot will come back to resting potential = hyperpolarization



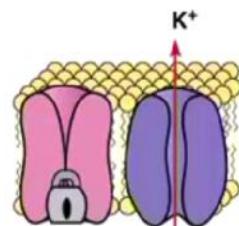
1. Resting state:
voltage-gated Na^+ channels closed. K^+ channels partly open (leaky).



2. Depolarisation: Na^+ channels open. An action potential begins when the neuron is depolarised to its threshold potential.



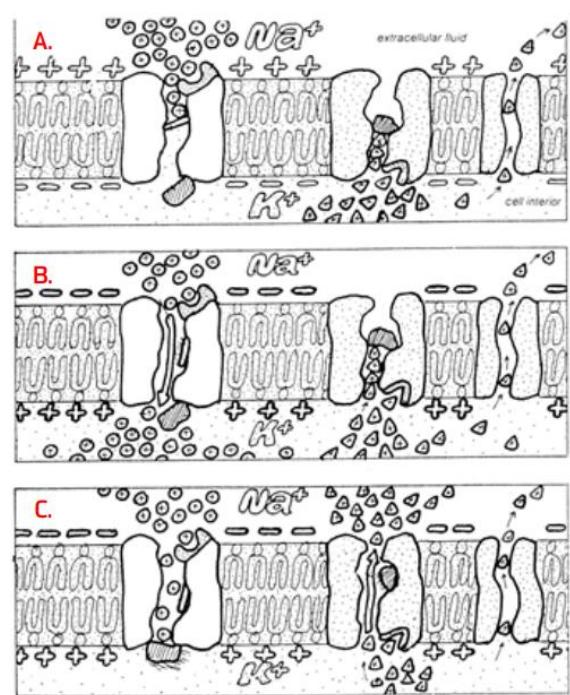
3. Repolarisation: Once the cell reaches its peak positive potential, Na^+ channels are inactivated and K^+ channels open. The cell repolarises to a negative membrane



4. Hyperpolarisation: K^+ channels remain open and Na^+ channels inactivated. The membrane potential becomes more negative than the resting potential

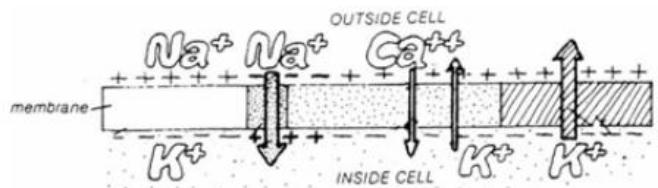
MEMBRANE AND ION CHANNELS

- All signals caused by chemical gradients and diffusion of cells among cell membranes
- Inside cell = high levels of K^+ ions and low levels of Na^+ ions
 - Opposite on the outside
- Membrane has separate ion channels for different ions
 - Ion channels differentiate between excitable tissue and normal tissue
 - Channels are picky and selective for specific ion species
 - Na channel only lets sodium ions go from outside to inside of cell
 - Effectively has three gates
 - One is voltage sensitive
 - Other is time sensitive
 - It will shut down after a certain period, independent of what voltage is across the membrane
 - Has an activation and deactivation gating variable
 - K channel only lets potassium ions go from inside to outside of cell
 - Single gate that opens depending on voltage across cell membrane
 - A,B,C are processes that occur when cell reaches 'threshold' (when a few sodium channels start to open)
 - (A) Na and K leak through membrane, bringing membrane back to resting potential
 - Na Opening → inside of neuron more positive (as voltage increases, all sodium channels open) → rush of Na into cell (B) → after a period, Na channels deactivate/close
 - More Na^+ increases positivity of channels → enough for K channels to open → repolarization (C): potassium ions diffuse into membrane → increasing negativity of channel interior
 - When potassium channels open and close slowly → Too much potassium goes inside = overshoot/hyperpolarisation
 - Refractory period = between time of hyperpolarisation to when membrane returns to resting potential



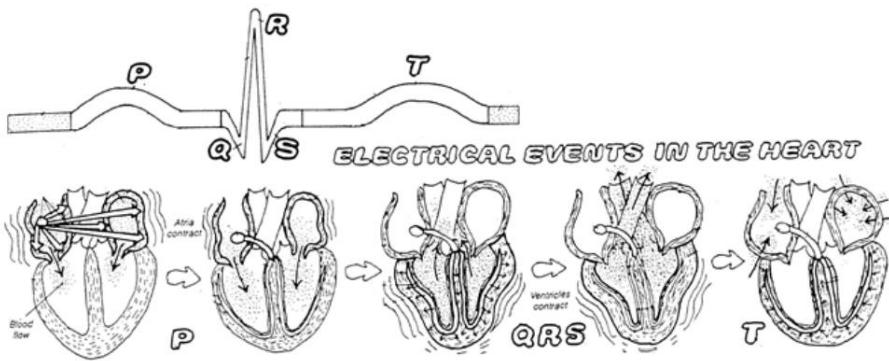
CARDIAC MUSCLE

- Duration of cardiac action potential is 100x more prolonged than in skeletal muscle/nerve impulse
- Long refractory period → Allows sustained contraction of cardiac muscle
- Plateau sustained by slow Ca^{2+} entry and slow K^+ flow out
 - When AP initiates, calcium ions flow as well
 - Ca ions maintain plateau ∴ elongated refractory period



ELECTROCARDIOGRAMS

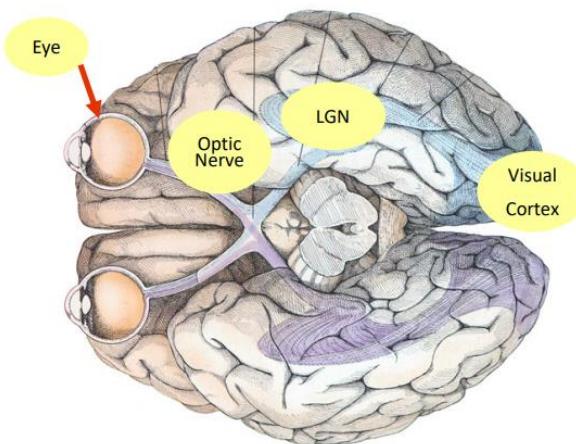
- Pacemaker in right atrium → regularly create AP → AP propagates from top to bottom of heart in controlled manner
- Controlled electrical activity allows ECG to form and be detected at body surface
- P – wave occurs when top of heart/atria contracts
- QRS complex
 - Ventricles contract
 - Repolarization of atria is hidden under QRS wave (due to relatively smaller size)
- T-wave occurs when ventricles repolarize/relax
- ECG records cell potential of all cells during heart beating at certain timings (mV)
 - Signals can be disrupted by noise (eg. Squeezing body parts or breathing)
- Interface is critical!!!
 - Shoving electrode nails in ourselves = v crude
 - # of functional channels increase = Better patient quality of life
 - Eg. Cochlear implants aren't perfect substitutes, as they can't distinguish between different pitches



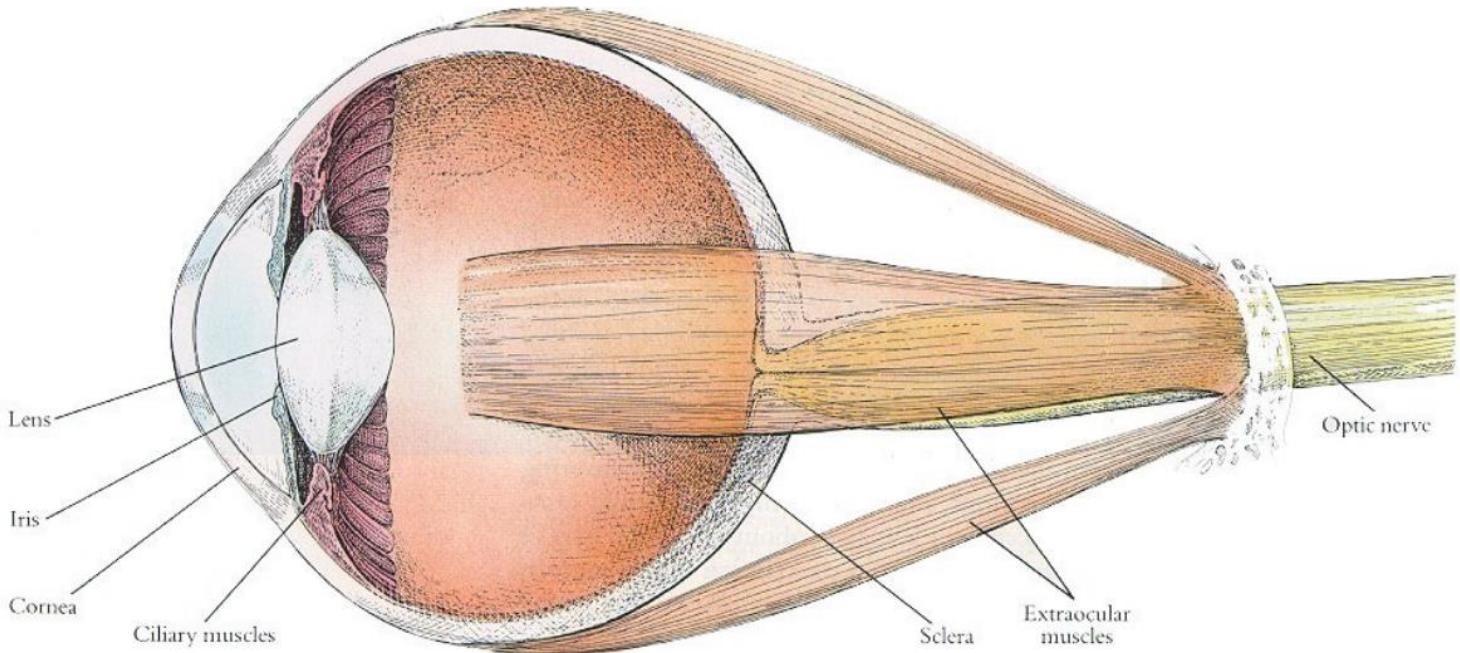
PART 2: NEURAL INTERFACING AND NEUROPROSTHESIS

THE HUMAN VISUAL PATHWAY

- Light signals → passes through cornea → lens → retina (back wall of the eye) → optic disk → lateral geniculate nucleus → visual
- Visual Cortex occupies a huge section of the brain because of the complexity of processing images
- Left side brain = process images from RIGHT EYE, and vice versa
- The function of non-retinal components of ocular anatomy is to maintain a focused and clear image of visual stimuli fixed on the surface of the retina
- Lens + eyes + muscles = maintain stable image when head shaking
 - Vestibulo-ocular reflex causes eye movement
- Three layers/tunics in eye structure
- TUNIC 1 = outside tunic = sclera and cornea
 - Sclera (white bit) maintains the eye globe
 - Anterior surface covered by conjunctiva (under eyelid; pink scaly thing)
 - Cornea (clear bit in front of eye) is non-vascular (no blood vessels) and continuous with sclera
 - Forms 15% of globe anterior
- TUNIC 2 = choroid, ciliary body and iris



- Choroid = 85% of globe anterior
 - Provides blood/nutrients to the retina; connects to ciliary body and iris
 - Loosely externally connected to sclera and internally connected to retina
 - Most vascular part of the body (greedy of energy)
- Ciliary body produces gel/aqueous humor and adjusts eye curvature to focus on nearby objects
 - Ciliary muscles help focus image on retina by changing its shape/curvature, but DOES NOT move lens back and forth

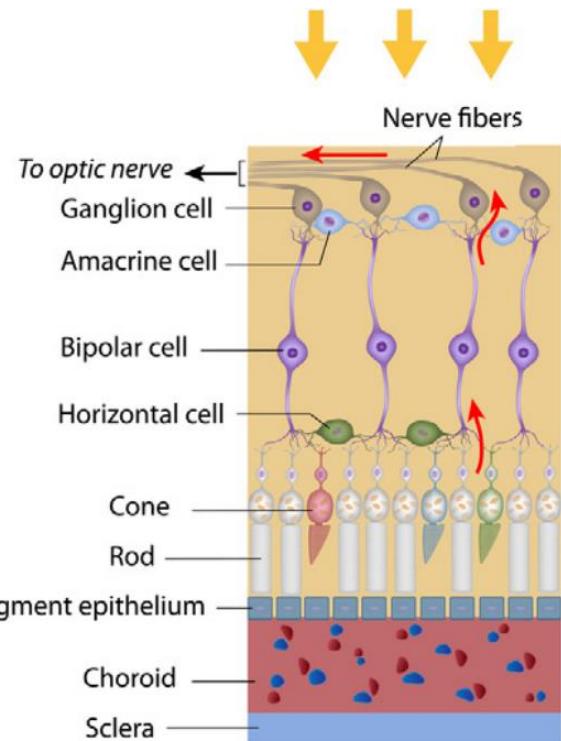


- TUNIC 3 = inner tunic = retina
 - Forms interior surface of eye from fovea centralis to ora serrata near ciliary body
 - Consists of 10 layers between choroid (outer surface) and vitreous humour (inner surface)
- CORNEA
 - Light enters at anterior surface of cornea
 - Approx. 2/3 of refraction/bending of light needed image focusing takes place at the air-cornea interface
 - Rest of about 1/3 occurs at lens
- LENS
 - Provides light bending power with the cornea
 - Main role is to change focal distance of eye, to allow focus on objects at various distances
 - Anterior surface changes shape, via contraction/relaxation of ciliary muscles
 - More Spherical = near objects
 - Flat = far
- IRIS adjusts amount of light on retina

THE RETINA

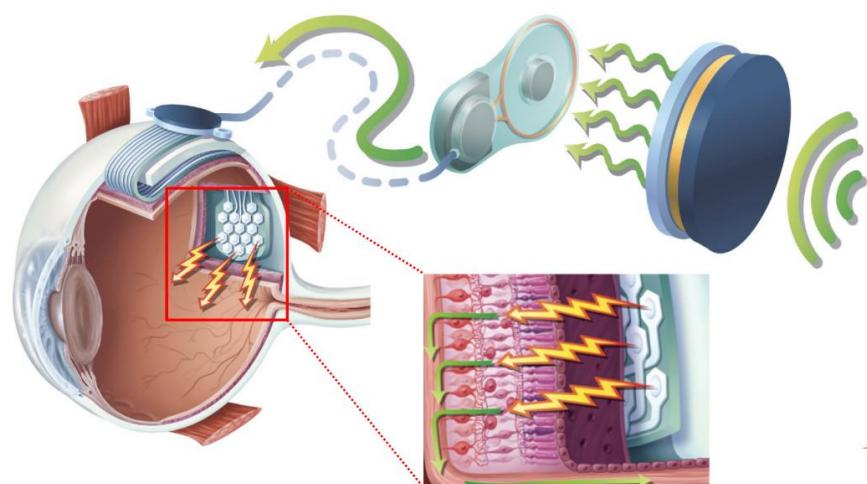
- From outer eye to inner:
 - Sclera
 - Choroid/blood supply
 - Pigment Epithelium (seal) provides nutrients from choroid to photoreceptors

- Photoreceptors = rods and cones
 - Cones = colored light, works best at relative bright light
 - Rods = peripheral vision, higher sensitivity
 - In dark, rods have Na^+ channels open and depolarize → activates bipolar cells → inhibits ganglion cells
 - Photoreceptors are still firing away while ganglion cells are turned off
 - In light, hyperpolarizes rods → inhibits bipolar cells → activates/excites ganglion cells
 - When dim light, cones shut off
 - Light → passes through cells → hits photoreceptors → photoreceptors transduce light into graded potentials → horizontal + bipolar cells create an image → feed it into ganglion cells
- Retinal ganglion cell layer
 - Retinal ganglion cell (RGC) is a type of neuron located near inner surface of retina, to receive info from photoreceptors via two intermediate neuron types: bipolar cells and retina amacrine cells
 - Contains axons (no dendrites) that collect at optic disk
 - Does not synapse directly with photoreceptors; goes via bipolar cells
 - Situated eat the anterior (front) of retina
- Intermediate cell layer
 - Between photoreceptors and ganglion cells
 - Consists of bipolar, horizontal and amacrine cells
 - In fovea (central vision); one-to-one correspondence between photoreceptor (cones) and GC
 - In periphery: 100-to-one correspondence between rods and GC [very concentrated]
- Bipolar Cells
 - Exist between photoreceptors (rod and cone cells) and GC
 - Transmits signals from photoreceptors to GC
- Sends difference in variables to the brain
 - Changes in light intensity
 - Differences in contrast



PART 3: BIONIC EYE

- During eye degeneration, photoreceptors are lost
- PROBLEM: Create a device that can electrical stimulate ganglion cells to replace lost transduction effects from photoreceptors
 - Only work for some retinal implants
- Retina can be implanted in 3-4 different places
 - Epi-retinal implant = interior front surface of retina



- Sub-retinal implant = detach retina; slide it behind retina and choroid
- Subprachoroidal implant = behind choroid/blood supply, further from retina, but simpler surgery :D
- REQUIREMENT: needs functioning ganglion cells and optic nerves → not a complete solution for eye defects

HOW DOES BIONIC EYE WORK?

- External camera/processing system sends radio frequency signals to implanted transmitter behind ear, providing energy and information
- No implanted battery due to high power consumption
- Signals = two wires connected to another electronic piece placed on top of eye globe exterior
- Electronic connected to electrode array threaded back of retina (suprachoroidal space)
- Current passes through electrodes → to choroid → through pigment epithelium → stimulates ganglion cells and possibly bipolar cell → sends signal to optic nerve and visual cortex

DEVICE LONGEVITY

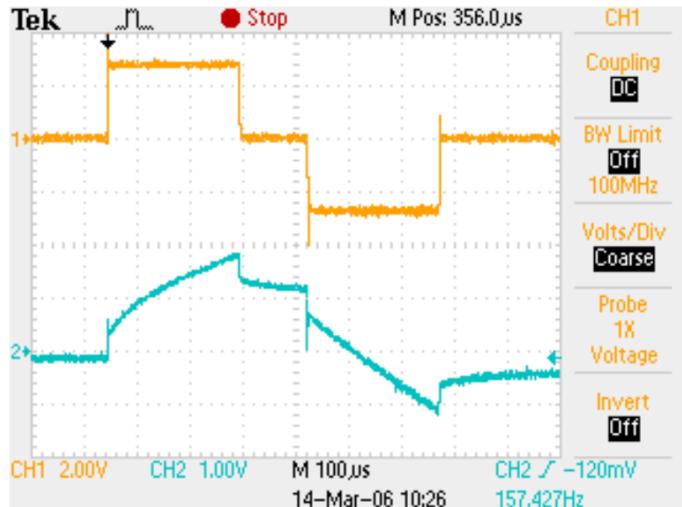
- Device coated with a layer of ceramic/platinum/polymer (potentially)/titanium → prevents condensation/leaking/toxicity
- Titanium lid/ring with ceramic base (Al oxide)
- Make it air/water tight
- Device should last about 50 years

IMPLANT ELECTRONICS

- 98 channels/sites of neural stimulation ∴ Charge balanced biphasic current waveform used for safe stimulation
- Needs chip to stimulate in safe manner
- When we inject a waveform (area under graph is amount of charge injected) → cells reach threshold and fire action potentials
 - Creates voltage at interface > than at water window
 - Water gets hydrolyzed
 - Electrodes change their pH and dissolve
 - Neural tissue can die off
- Thus, equal and opposite charge needs to be injected to keep neutrality

SURGICAL PLACEMENT

- Device sits within stable “pocket”, behind choroid
- Significantly simplifies surgical approach



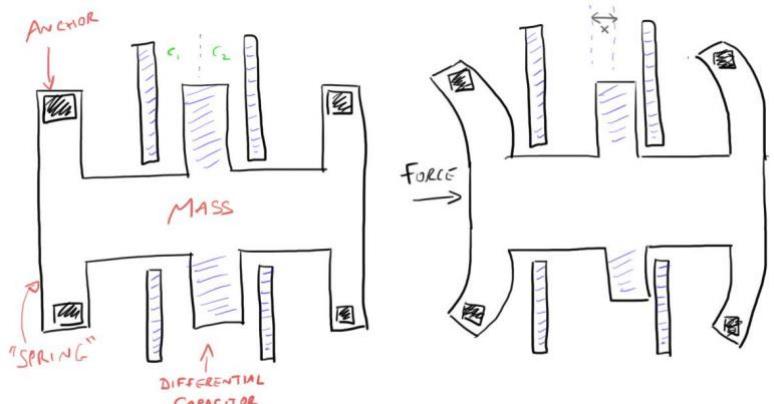
Lecture 8 – Monitoring human movement using wearable sensors

PART 1: PHYSICS BEHIND SENSORS AND FUNCTIONALITY

NEWTONS SECOND LAW:

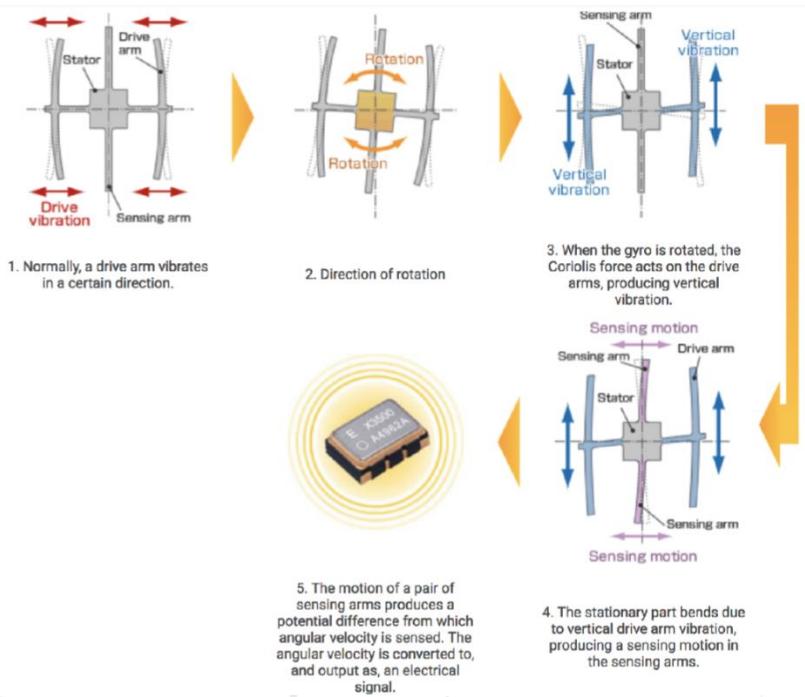
- Accelerometer
- $F = ma \rightarrow$ How we measure acceleration in systems
- Hooke's Law : $F = -kx$

- Amount of force required to stretch a spring, proportional to the distance needed to be stretched
- If we can measure displacement of the spring, we can figure out the force
- Spring = beam
 - Force on spring → spring bends → amount of force depends on 2nd law, $F = ma$ ($= -kx$) → if mass is known, acceleration can be found from displacement (from the bending)
- Displacement is determined via the different capacitors
 - Different distances from middle plate to outside plate, as well as, relative charges (ie. intensity of attraction)



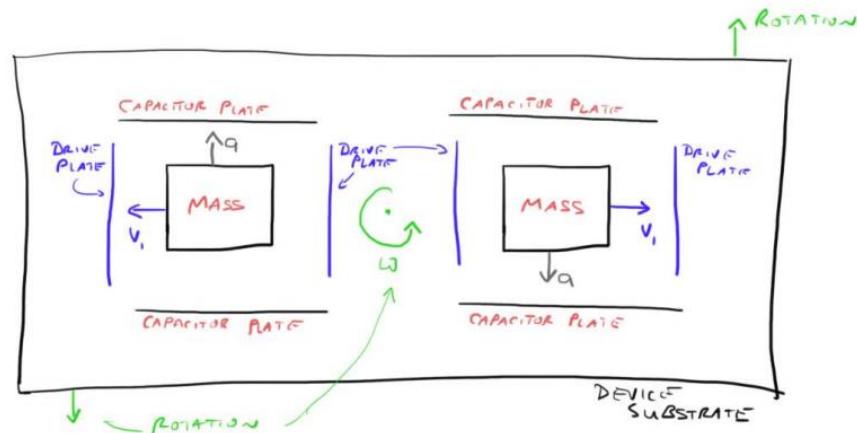
GYROSCOPES

- Used to determine direction/way of rotation/angular velocity
 - Senses rotation motion + changes in orientation
 - Via change of angle
 - Consists of a wheel or disc that spins rapidly about an axis, with freedom of movement (can change direction)
 - Since orientation of axis is not affected by tilting the mount, it can provide stability or maintain a reference direction in navigation systems, automatic pilots and stabilizers
- Coriolis Effect
 - Pseudo Force effect (force acting on object in rotating frame of reference)
 - Inertial: Acts on objects in motion relative to rotating reference frame
 - Rest Frame: in room
 - Spinning disk in room
 - Put hand over disk and fire a bullet
 - Rotation of disk doesn't affect bullet's trajectory; bullet travels straight after being fired
 - Rotational frame: Sitting on disk
 - If hand is put up and a bullet is fired, to me; bullet is going straight up
 - From rest POV, bullet is curving away



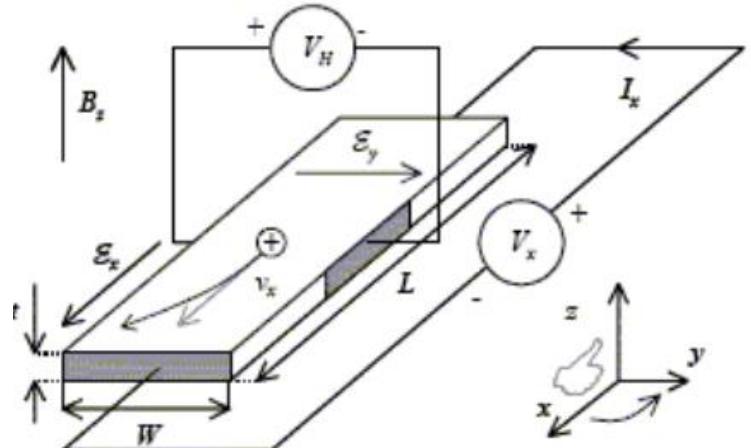
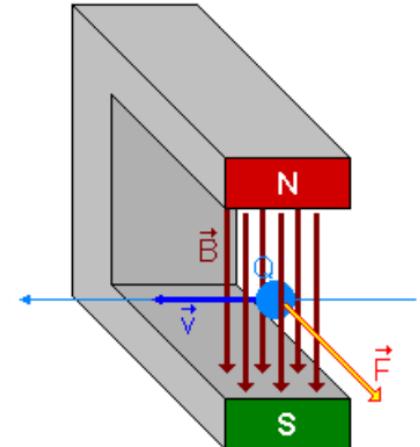
MEMS GYROSCOPE

- A differential capacitor (same as accelerometer) to measure displacement
- Mass in capacitor plates shake/vibrate left and right (using coulombs laws) → aka. Vibrating gyroscopes
- But once rotated in any way, coriolis effect takes effect
- When mass moves outward, it accelerates to keep up with the frame. When mass moves to centre, little acceleration needed to keep up with rotation
 - Stationary: mass moves left and right
 - Rotating: mass is deflected up and down
- Can measure displacement for gyroscope via differential capacitor
- Utilizes 2x mass system to keep phone balanced (ie. not vibrate). During movement, mass move perfectly out of phase



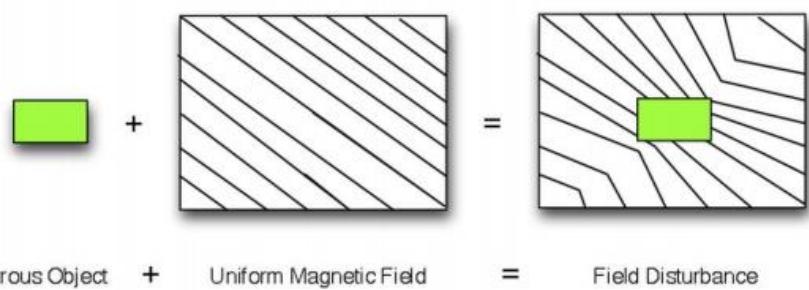
MEMS MAGNETOMETER – LORENTZ FORCES

- Easily lost from adding rotations from gyroscopes → magnetometer tells us where we fact
- Lorentz force – if a charged particle is moved with some velocity in a magnetic field, it will feel a force
 - $F = V \times B$ (cross product)
 - Where F is perpendicular (RHP)
- Application of lorentz force is the hall effect
 - Set up a voltage source, that sends current through a circuit with a Si semi-conductor (higher resistance than wire, but low enough for current to flow; if current is too high, circuit would explode)
 - Charge moves with velocity → experiences Lorentz forces → charge piles up/pushed to one side of conductor → charge distribution has one side more negative than the other
 - = voltage, indicates presence of magnetic field
 - Needs one in each direction (x,y,z) to detect B -field



ISSUES WITH MEMS MAGNETOMETERS

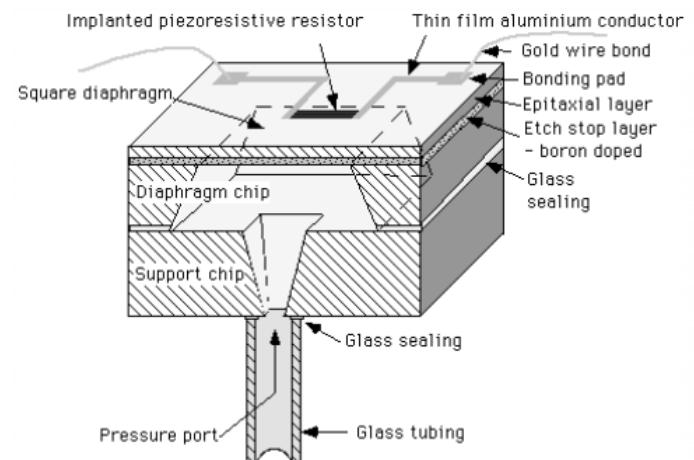
- Calibration problems → too many magnetic distortions
- Soft Iron = interaction of external field with board
 - Ferromagnetic material on sensor board → material distorts field lines



- Hard iron = fixed magnetic field on board
 - o Magnets on sensor board
 - o Permanent distortion = always there, always measuring its magnetic field
- Magnetic Declination
 - o Earth's magnetic field is distorted around Earth → compass does not point exactly magnetic north
 - o Declination = angle variation on horizontal plane from actual north m
- Magnetic inclination
 - o Angle made HORIZONTALLY by Earth's magnetic field lines
 - o At equator, magnetic field goes straight across surface → reliable indication of North
 - o South pole = almost 90°

MEMS BAROMETER

- Chamber → sealed air inside → implant piece of resistor on diaphragm (thin skin across hull) → resistor changes resistance when stretched
 - o As air pressure, outside of chamber, changes, diaphragm:
 - Stretches when moving up, contracts when moving down
 - Measures altitude (but: needs to be calibrated)
 - CONs: pressure changes according to weather (interference)



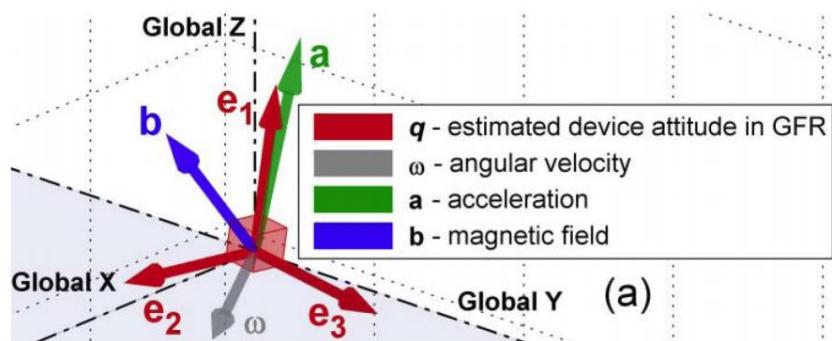
GPS (Global Positioning System)

- Multilateration; algorithms of distances to determine position
- Needs 4 satellites
 - o All satellites contain atomic clocks, synched up (accounting for time delay) → sends signal with time stamp → phone determines distance between satellites from differences in time stamps
- Special relativity slows time for travelling satellites → time delay subtracted

PART 2: MATHS OF ROTATION

- Needs to figure out angles between vectors and how to rotate axis angles to determine orientation, given with the data in the gyroscope
- Dot (scalar) product
 - o Determines angle between vectors
- Cross (vector) product
 - o Finds vector perpendicular to two vectors
- Angular Velocity
 - o Angular distance = angle in radians
 - o Angle = $\frac{\text{distance along arc}}{\text{radius}}$
 - o Angular velocity = $\frac{\text{angle around axis of rotation}}{\text{second}}$
 - Speed is perpendicular to $\frac{\text{axis of rotation}}{\text{radius}}$ [how fast, it is spinning along the arc]

Using the gyroscope



QUATERNIONS

- Extension of complex numbers:

$$\mathbf{q} = q_r + q_x \mathbf{i} + q_y \mathbf{j} + q_z \mathbf{k}$$

- Can be used to do rotation by θ about an axis \mathbf{u} if written in following way:

Unit vector can show direction

$$\mathbf{q} = \cos \frac{\theta}{2} + \sin \frac{\theta}{2} (u_x \mathbf{i} + u_y \mathbf{j} + u_z \mathbf{k})$$

where $\|\mathbf{u}\| = \sqrt{u_x^2 + u_y^2 + u_z^2} = 1$, a unit vector

- Encodes 3D rotation in the word (especially the u-quaternion)

AXIS – ANGLE ROTATIONS = take a point and rotate it around a given vector in 3D space

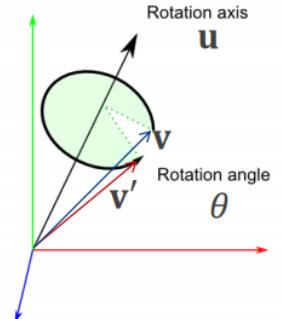
- U = rotation axis
 - Needs unit vector form (divide each component by vector's total absolute length)
- v and v' are endpoints of rotation
- Takes the vector with a '0' real part at front
- Rotation is encoded in q
 - Need to find q and its quaternion conjugate
 - Put it at the start and end = rotation
 - Utilizes the second equation
- Using RH Grip Rule

Do a rotation of point $\mathbf{v} = v_x \mathbf{i} + v_y \mathbf{j} + v_z \mathbf{k}$ by θ radians around the unit vector \mathbf{u} :

$$\mathbf{v}' = \mathbf{q}(0 + v_x \mathbf{i} + v_y \mathbf{j} + v_z \mathbf{k})\mathbf{q}^*$$

$$\mathbf{v}' = \left(\cos \frac{\theta}{2} + \sin \frac{\theta}{2} (u_x \mathbf{i} + u_y \mathbf{j} + u_z \mathbf{k}) \right) \cdot (0 + v_x \mathbf{i} + v_y \mathbf{j} + v_z \mathbf{k})$$

$$\cdot \left(\cos \frac{\theta}{2} - \sin \frac{\theta}{2} (u_x \mathbf{i} + u_y \mathbf{j} + u_z \mathbf{k}) \right)$$



The rules!

$$\mathbf{i}\mathbf{j} = \mathbf{k}, \quad \mathbf{j}\mathbf{i} = -\mathbf{k},$$

$$\mathbf{j}\mathbf{k} = \mathbf{i}, \quad \mathbf{k}\mathbf{j} = -\mathbf{i},$$

$$\mathbf{k}\mathbf{i} = \mathbf{j}, \quad \mathbf{i}\mathbf{k} = -\mathbf{j},$$

$$\mathbf{i}^2 = \mathbf{j}^2 = \mathbf{k}^2 = -1$$

KALMAN FILTER

= random guess of variables from noisy data (eg. orientations, some angles, progression of data as time progresses)

- Figure out orientation → subtract gravity = just acceleration due to movement
- Integrate it twice to determine position (although inaccurate, due to unknown constants)

DEAD RECKONING

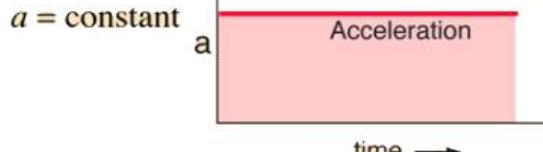
- Sensor on foot → every time, foot hits ground = 0 velocity → get a trace of vertical vs forward position (x metres)

Starting from rest at position zero

$$y = \frac{1}{2} at^2$$

$$v = at$$

$a = \text{constant}$



More generally

$$y = y_0 + v_0 t + \frac{1}{2} at^2$$

$$v = v_0 + at$$

Velocity is equal to the slope of the position curve.

Acceleration is equal to the slope of the velocity curve.

Lecture 9 – Biomaterials and Tissue Engineering

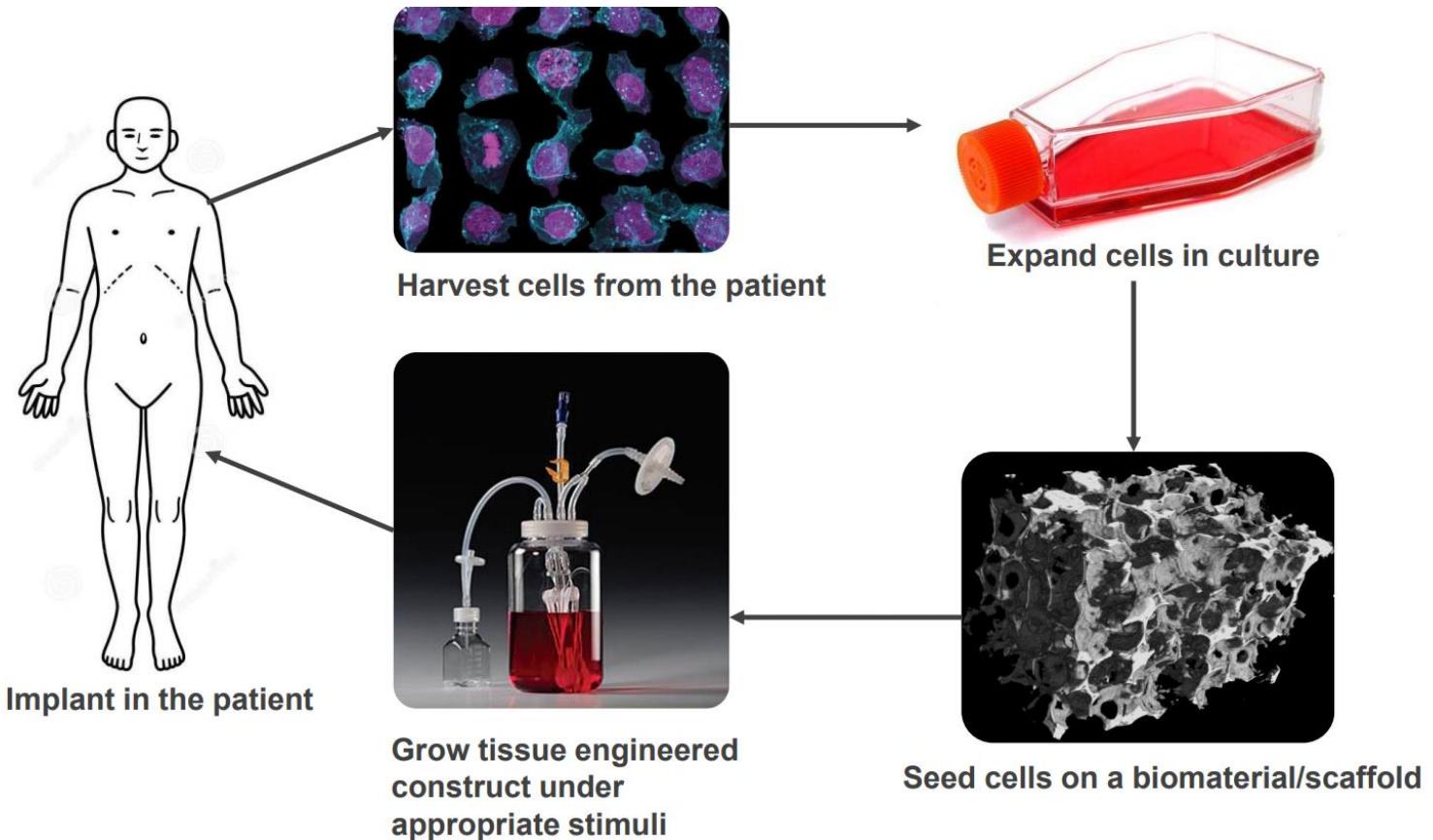
WHAT IS IT?

- Application of engineering principles and life sciences towards development of biological substitutes to restore, maintain, or improve tissue function or a whole organ
- Creation of new tissue for the therapeutic reconstruction of the human body
- Controls and stimulates target cells by a combination of molecular and mechanical signals, only to manipulate their functionality
- Replace damage or dysfunctional tissue, as well as, an organ replacement

MAIN COMPONENTS REQUIRED IN TISSUE ENGINEERING

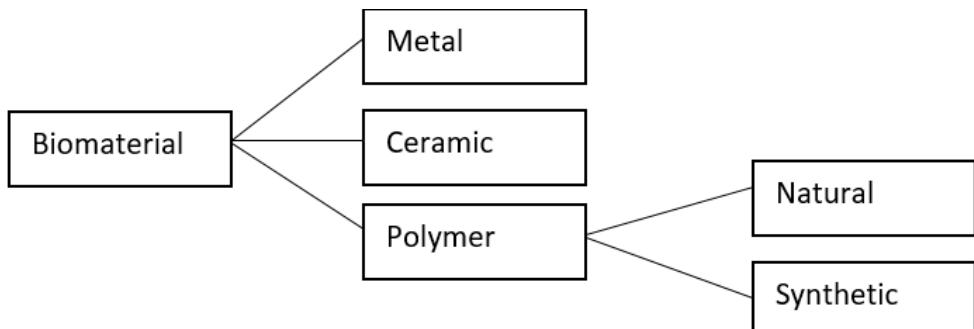
- Sample cells from subject/donor; provides building blocks for engineering tissues and organs
- Cell scaffold; provides structure for cells to bind into until cells differentiate into desired tissue/organ
- Signal producers; stimulate growth of cells and their specialization into desire tissues or organs, as well as, ensuring proper functionality of engineered tissue

HOW DOES IT WORK?



BIOMATERIALS

- ‘Material intended to interact with biological systems to evaluate, treat, augment or replace any tissue, organ or body functionality’
- Some examples include; films, sponges, fibres, 3-D printed materials

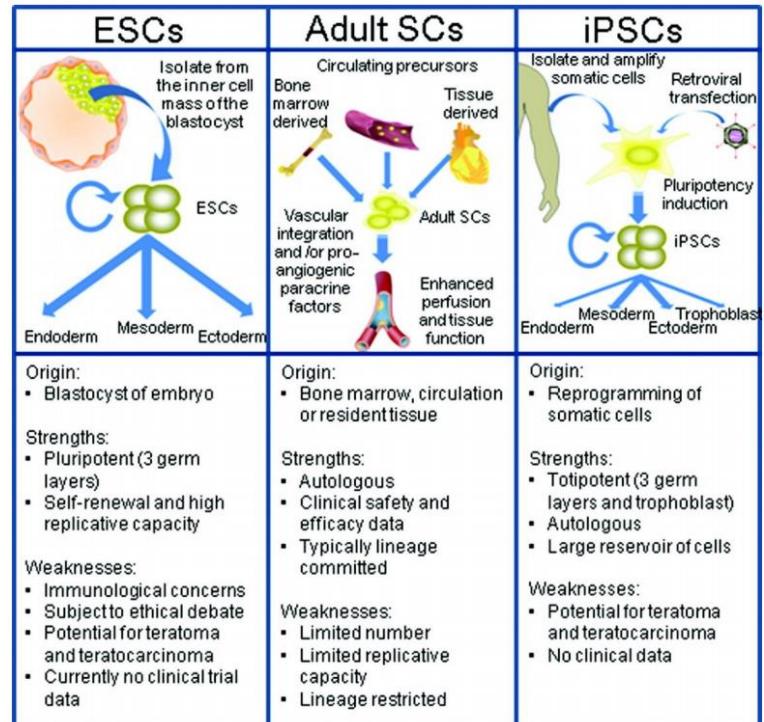


NATURE VS SYNTHETIC SCAFFOLD MATERIALS

Natural	Synthetic
<ul style="list-style-type: none"> - Ease of binding and architecture of tissue/organ already pre-determined - Since body able to recognize its own collagen cells, additional substances not required to promote binding of cells to scaffold - Hard to separate cells from collagen 	<ul style="list-style-type: none"> - Relatively inexpensive and easier to design and obtain. - Material may be considered foreign to body, immune response may be initiated against the synthetic scaffold - Requires the use of inhibitors or hormones to increase chance of being accepted by a patients' body.

CELLS

- 'An autonomous self-replicating unit that exists as a functional independent unit of life, or a sub-unit of a multicellular organism, only to carry out a particular function towards the organism as a whole'
- Cell culture
 - o Cells from various tissue of plants and animals grown and cultured in an artificial environment outside the body
 - o Involves:
 - Harvesting of individual cells from specific tissue
 - Maintaining cells in an incubator at body temperature (37°C) in a plastic or glass flask
- Type of cells:
 - o Differentiated
 - o Stem Cells (seen on right)



DONOR VS PATIENT'S OWN CELLS

Donor	Patient
<ul style="list-style-type: none"> - Allows preservation of patient tissues and organs - Reduces invasiveness towards patients when conducting medical procedures. - Risk of rejection of donor cells once implanted in patient - Lack of suitable donors - Need to screen donors for medical conditions 	<ul style="list-style-type: none"> - Little to no risk of cell rejection by patients' body - Less processing required to obtain desired function - Limited donor sites to obtain cells and tissues from patient - Risk of infection when extracting tissue from patient, wounds produced during extraction - Underlying patient conditions may make cell extraction difficult/infeasible

SIGNALS WITHIN TISSUE

- Biochemical, eg. Growth factors
- Mechanical, eg. Strain bioreactor
- Electrical, eg. Electrical stimulation

Lecture 10 – Computational Stimulations in Bioengineering

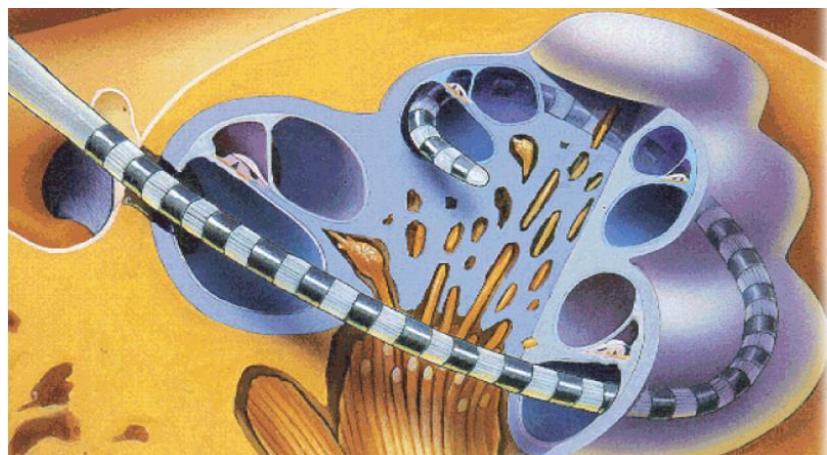
MODELLING

- Representation of a physical system
 - o Formulation of mathematical/computational representation of a physical system
- Can predict behavior of a system
- Typically solve on computer
- In bioengineering → study behavior of complex physiological systems and interactions of external devices
- Examples of modelling:
 - o Reading electrical signals from heart pacemakers
 - o Electrical stimulation of ganglion cells in vision prosthesis (testing a range of electrical stimulation profiles and how they behave)
 - o Electroconvulsive therapy (sending a current through the brain, treats depression, trying to study path of currents through brain and how ECT works)
 - o 3D printing by orthopedists when replacing parts
- Used to design electrodes and where to position electrodes

Lecture 11 – Sensory neural prosthesis and transcutaneous energy

FIRST COCHLEAR IMPLANT (1978)

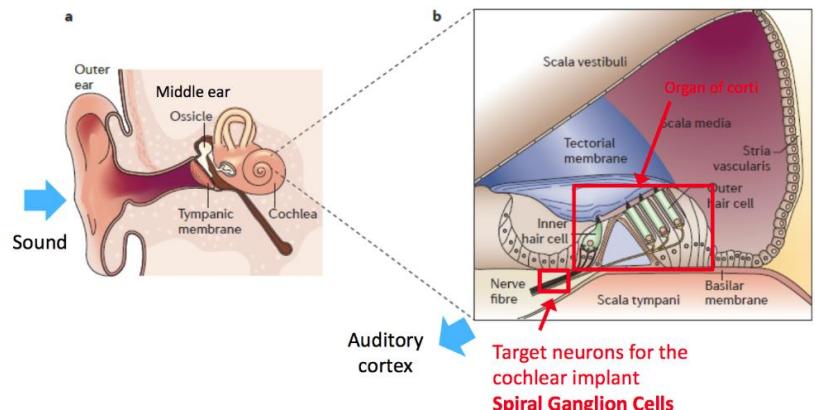
- Electrode array goes into cochlear
- Made from copper coil = inductor
 - o Encapsulated in epoxy (may not have been medical grade)
 - o Altogether went into electrode array
- Understanding risks:
 - o By today's standards, device would not be commercially marketed/implanted
 - o Back in 1978, had a huge demand → advocated for use
 - o 2/3 prototypes failed, but since one worked → Cochlear still gained approx. 65% of world market
 - Implanted in > 350,000 people
- Reference to picture (right)
 - o Cochlear = bony material
 - Size of tip of pinky
 - o Need some material that fits in, loops around and draws out electrical stimulation from electrodes
 - o Target tissue = yellow = spiral ganglion cells
 - Collect and form auditory nerve
 - Goes to sound centers of brain to be interpreted
 - o Action potential



- Needed to transport signals

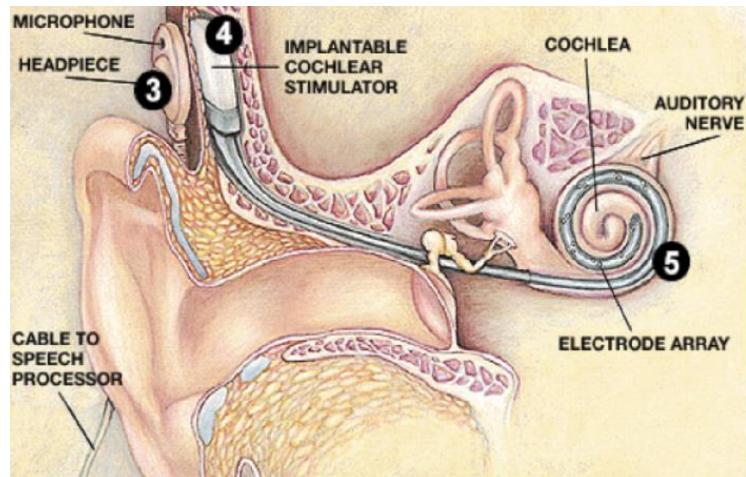
ORIGINS OF NEUROMODULATION

- Manipulate cells' behavior by changing the extracellular potential
- Eg. Applying a voltage relative to the inside of a cell = membrane becomes charged
 - Action potential → enables certain functions in body to occur



SENSORINEURAL HEARING LOSS

- Sound hits the tympanic membrane → vibration
 - Ossicle augments vibration → creates greater mechanical movement on middle ear
 - Middle ear pushes onto cochlea, moving fluid around → fluid movement bends into inner hair cells → bending generates action potential ∴ sending signals to the brain
 - OCCURS IN THE ORGAN OF CORTI
- Target neurons for implant = spiral ganglion cells
 - Attached to hair cells
 - In diseases (eg. Meningitis) where hair cells are killed → it cannot cause action potential from hair bending
- If auditory nerve is present and functional, it can be electrically stimulated → can detect sound
- Cochlear implant system
 - Outside = microphone + headpiece
 - Implantable cochlear stimulator → cable → through round window, into cochlear → electrically stimulate various positions of cochlear

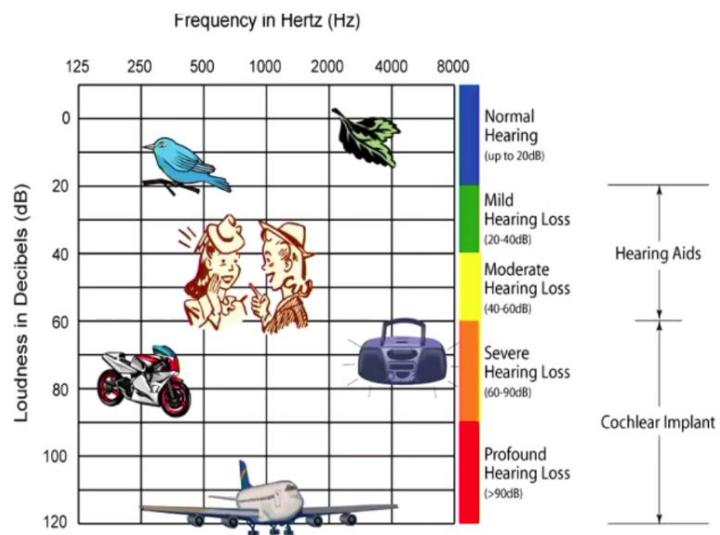


THE BIONIC EAR

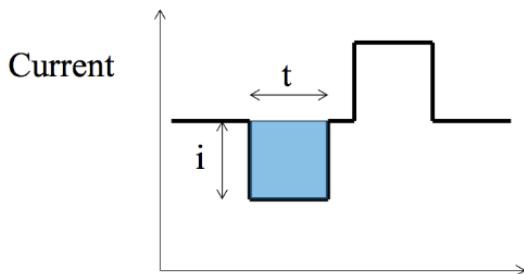
- Stats:
 - Approx. 120 million are hearing impaired (Approx 1 million in Aus.)
 - 2% are fully deaf → (2.4M worldwide, approx. 20K in Aus.)
 - FDA, initially let Cochlear implant into those profound deaf, as they thought it did more damage than good

THE STIMULUS WAVEFORM

- Use constant current pulses

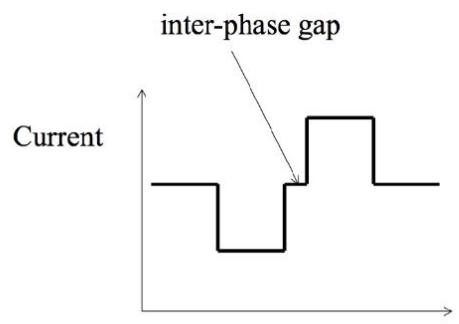


- Other devices typically use voltage
- Phase 1 does all the work
 - Gets action potential firing by injecting charge (coulombs)



Charge = current (i) x time (t) (coulombs)

- Inter-phase gap
 - Can be adjusted to what is most effective
 - Needed to allow time for action potentials to propagate down to designated area

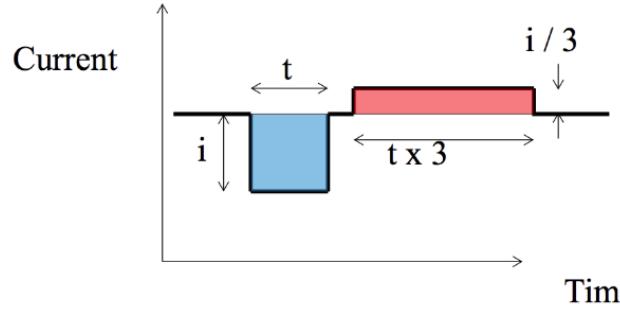


Time

Phase 1 starts the stimulation process. The onset of phase 2 has an influence on what happens next. The inter-phase gap controls this onset.

- Phase 2
 - Charge recovery = reverse the induced charge and restore neutrality → ear is stimulated again without difficulties arising in electrochemistry
 - Without it, cause buildup of random chemicals and unwanted substances
 - Ideally, has the same amount of charge in second phase
 - But, in reality, not exactly equal due to ions/particles moving away from electrode site
 - Can still cause electrical stimulations
 - Solution: reduce current amplitude but have a pulse occur over a longer amount of time (area = 0)

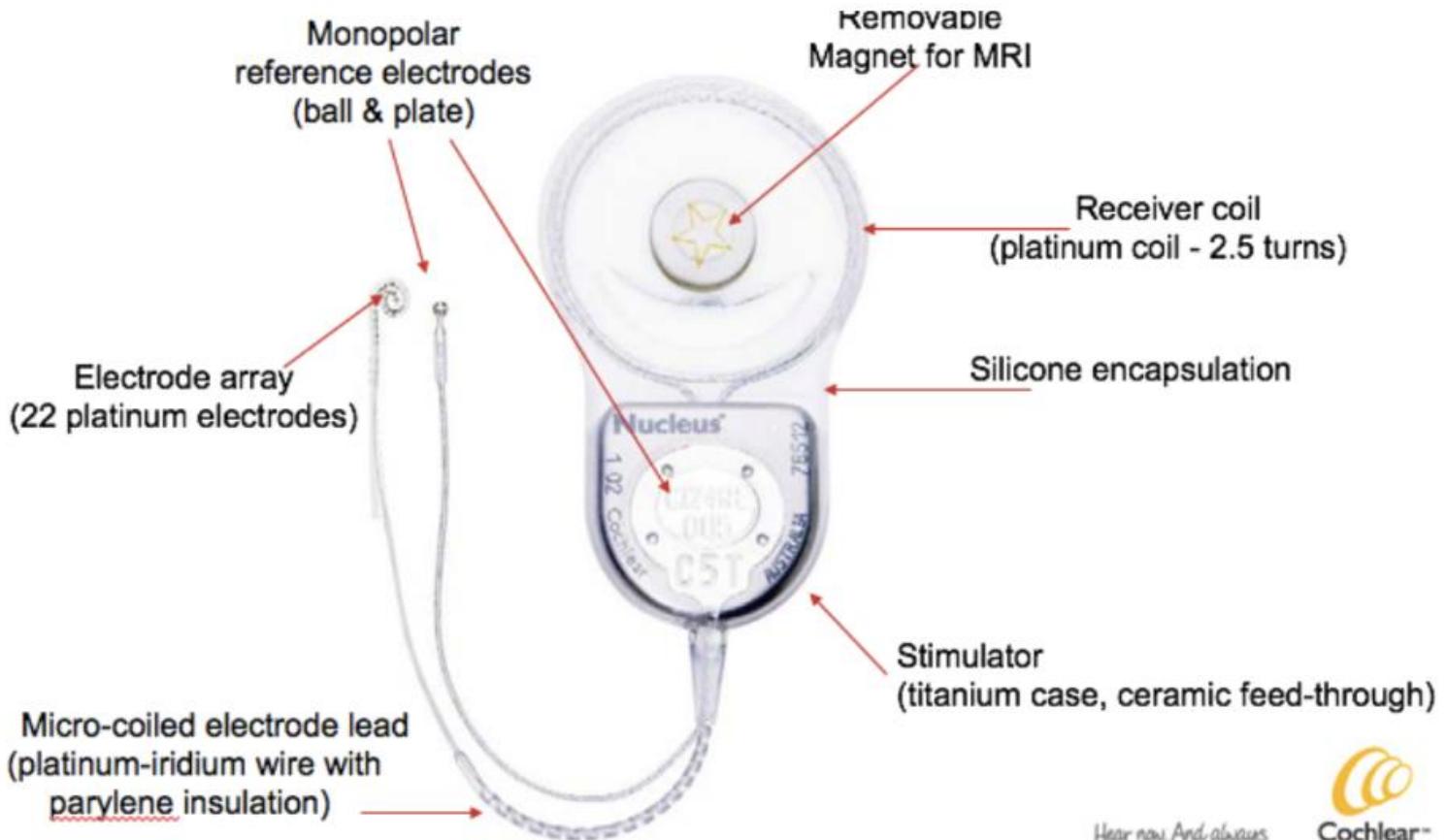
$$\text{blue square} - \text{red rectangle} = 0$$



Time

Less likely to cause secondary stimulation – but takes longer

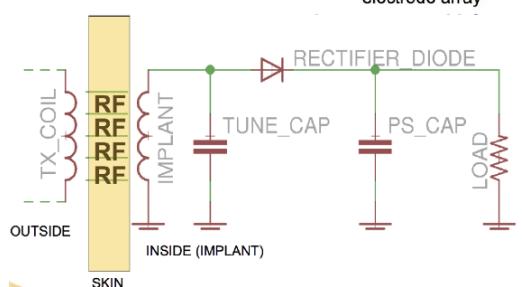
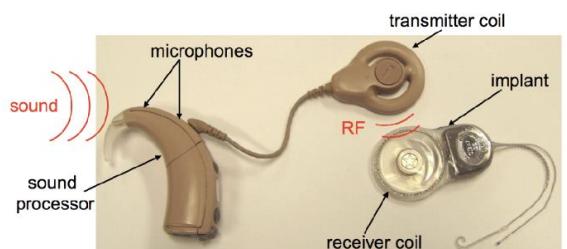
- Charge = area under curve (sum must = 0, to be neutral)
- Inter-stimulus gap
 - Separation between pulses
 - Limited to how quickly you can feed information, and how quickly the electrodes are serviced
- Stimulation can only occur once at a time
 - Eg. If you have 22 electrodes, only one can be stimulated at a time



 Cochlear

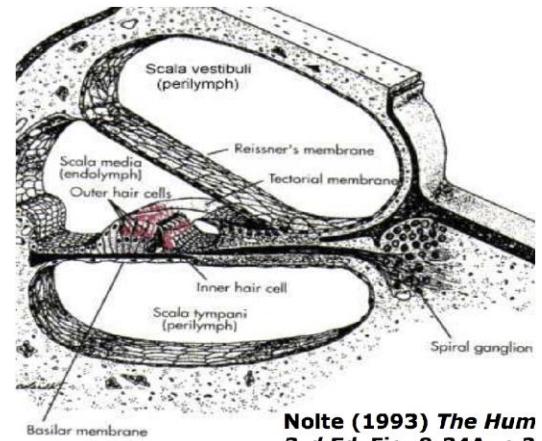
Hear now. And always.

- 24 channels = 22 channels on electrode array + little monopolar reference electrode (ball + plate)
- Monopolar ref. electrodes = return path for the negative return of electrical stimulation
- Contact materials = silicone, titanium and platinum
- All electronics are placed in a little capsule = hermetic chamber
 - o Connects to each of little wires
- Sound processor has 2x microphones
 - o Picks up surround sound
 - o Assumes most important sound is in front, so sound received = front minus behind sound
 - o Sound processor → sends instruction and power to the RF link
- RF link
 - o Via inductive coupling
 - o Outside TX (transmitting) coil → RF signals go through skin → implant (circuitry grabs energy off) → detects when energy is turned on/off
 - o Use RF coil to prevent infection from implanting
 - o Don't implant battery (due to big size); coils are very small → allowing babies to wear them



ANATOMY OF COCHLEA

- Scala media (media = middle)
- Scala vestibula
- Scala tympani
 - o Tympani membrane is where hair cells are excited
 - o Target area = spiral ganglion cells
- In picture [right]; electrode array (grey) = metal
 - o If e-pulses are emitted from metal, we can excite spiral ganglion cells and send signals off to the brain to be interpreted as sound
- Electrode array
 - o Used to be straight, but presently curled
 - o Cochlea is curled
 - o Allows electrode to get close as possible to spiral ganglion cells
 - o Electrical stimuli is directed inside curl of electrode; when it was straight, it will go outside
- BUT: looking at x-ray image, there is still so much of cochlea that isn't reached
 - o Consequences:
 - Only detecting high pitch/frequency (low frequency = long wavelength penetrating through the deeper end of the cochlea
 - o Goal:
 - Have widely spaced electrodes throughout the cochlea
 - Hear all sounds of the spectrum
 - o Electrodes are limited to a range of frequencies; not a 1:1 correspondence (eg. Piano keys slammed hard)
 - o In 25 years, < 7% of devices have failed



Nolte (1993) *The Human Brain*

