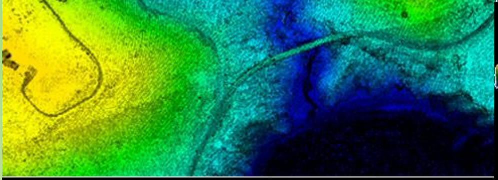
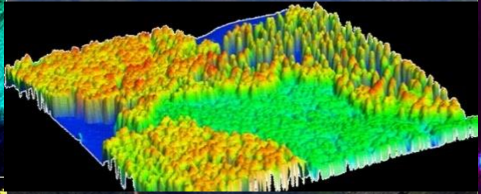
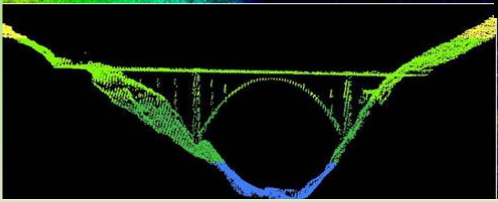
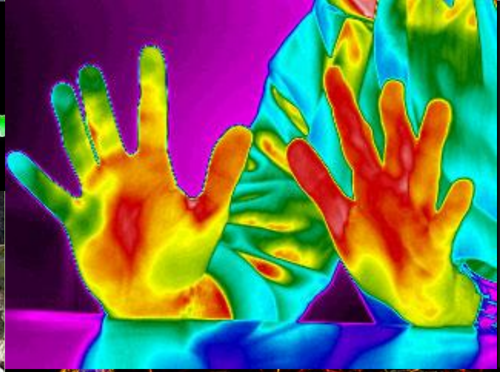
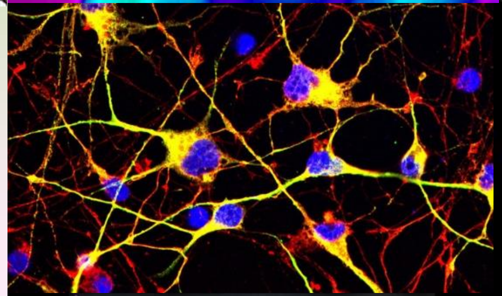






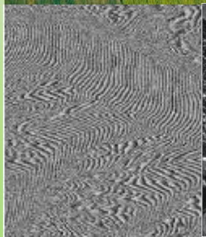
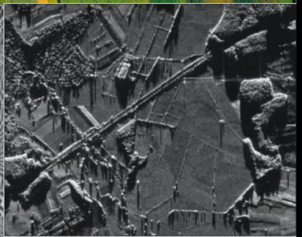
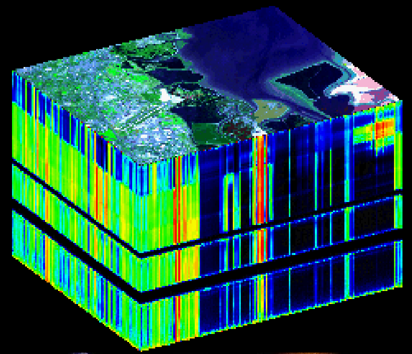
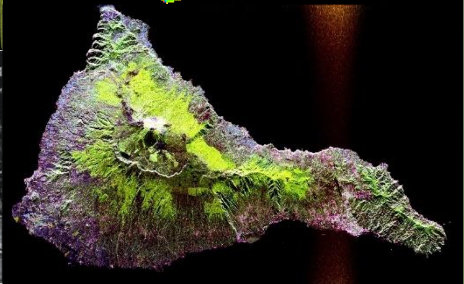

Ciências ULisboa

Imaging Systems

Engineering Physics



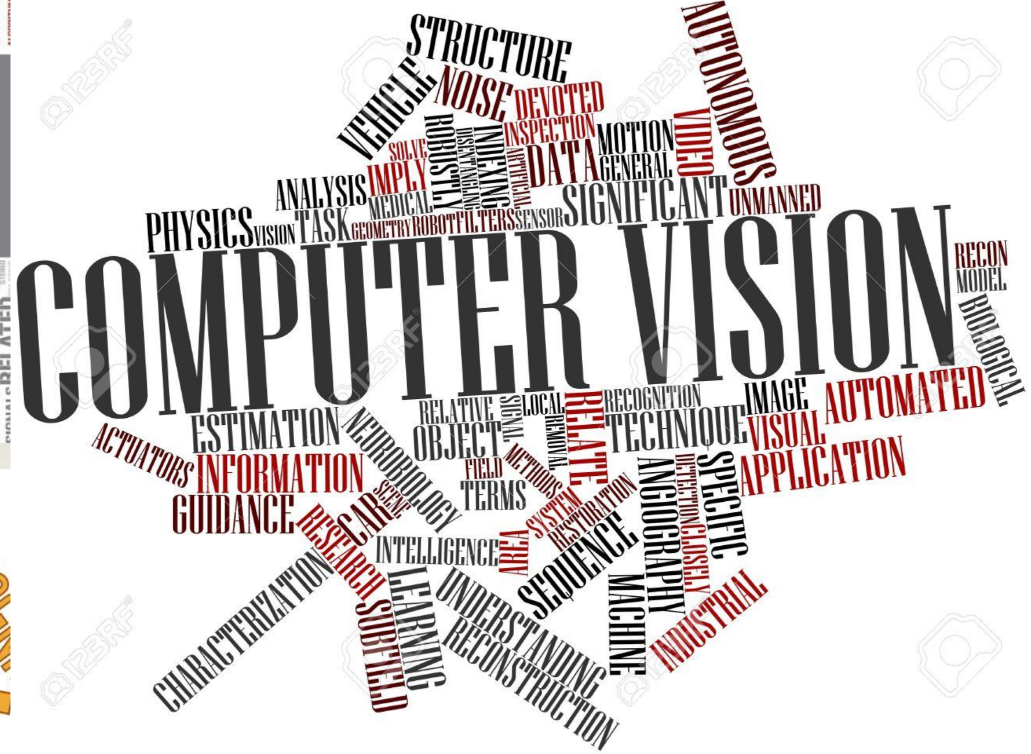


José Manuel Rebordão
João P. Coelho

2019/2020


VISION
COMPUTER
METHODS
MACHINE
APPLICATIONS
SYSTEMS
SPECIFIC
IMAGE
IMAGES
DATA
BASED
PROCESSING
SUCH
ANALYSIS


COMPUTER VISION
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AUTONOMOUS
VEHICLE
NOISE
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INSPECTION
MOTION
DATA
SIGNIFICANT
UNMANNED
PHYSICS
ANALYSIS
TASK
ESTIMATION
INFORMATION
GUIDANCE
TECHNIQUE
AUTOMATED
VISUAL
APPLICATION
SEQUENCE
INDUSTRIAL
CHARACTERIZATION
RECONSTRUCTION
UNDERSTANDING
INTELLIGENCE

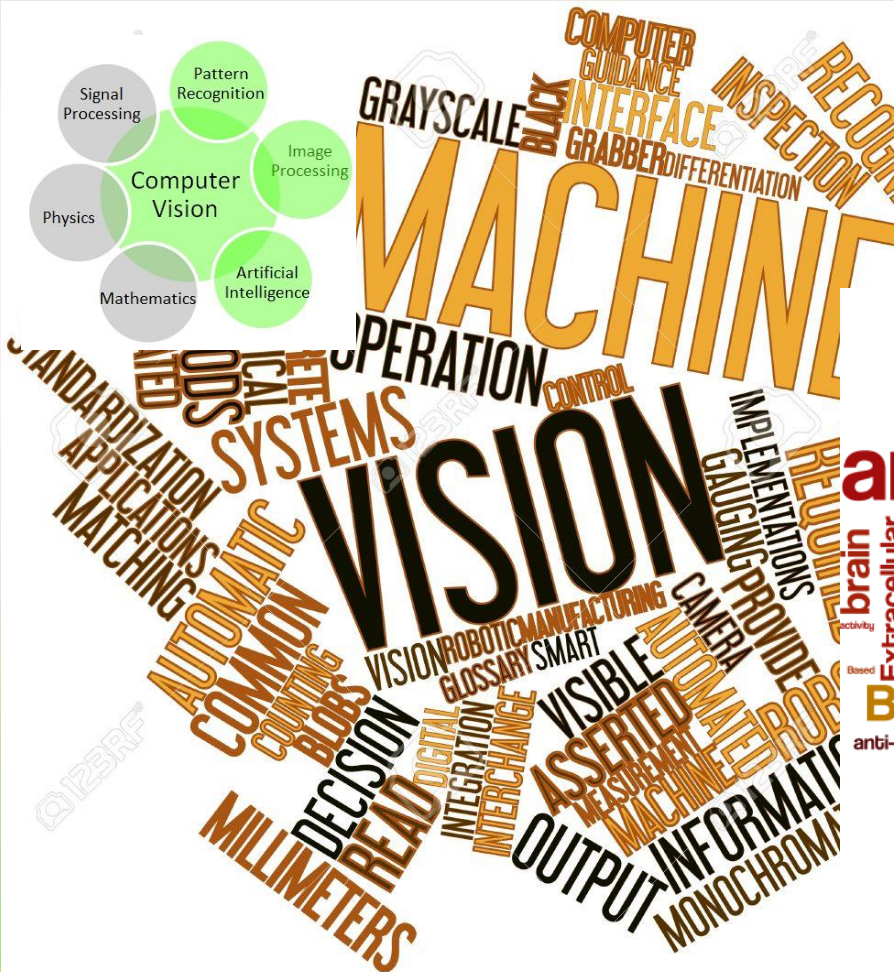
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Image Processing
Computer Vision
Physics
Artificial Intelligence
Mathematics
MACHINE
VISION
GRAYSCALE
INTERFACE
INSPECTION
GRABBER
DIFFERENTIATION
OPERATION
SYSTEMS
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COMMON
DECISION
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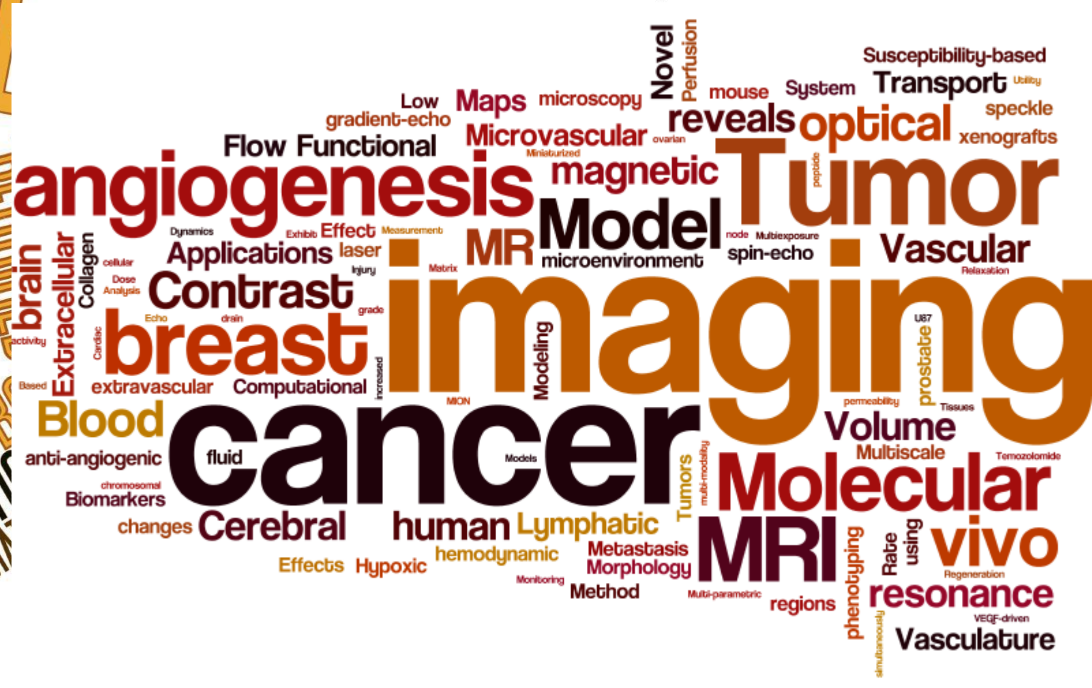
MILLIMETERS
INFORMATION
MONOCHROMATIC
VISIBLE
ASSERTED
CAMERA
PROVIDE


imaging
cancer
Tumor
angiogenesis
breast
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Molecular
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vivo
Contrast
Blood
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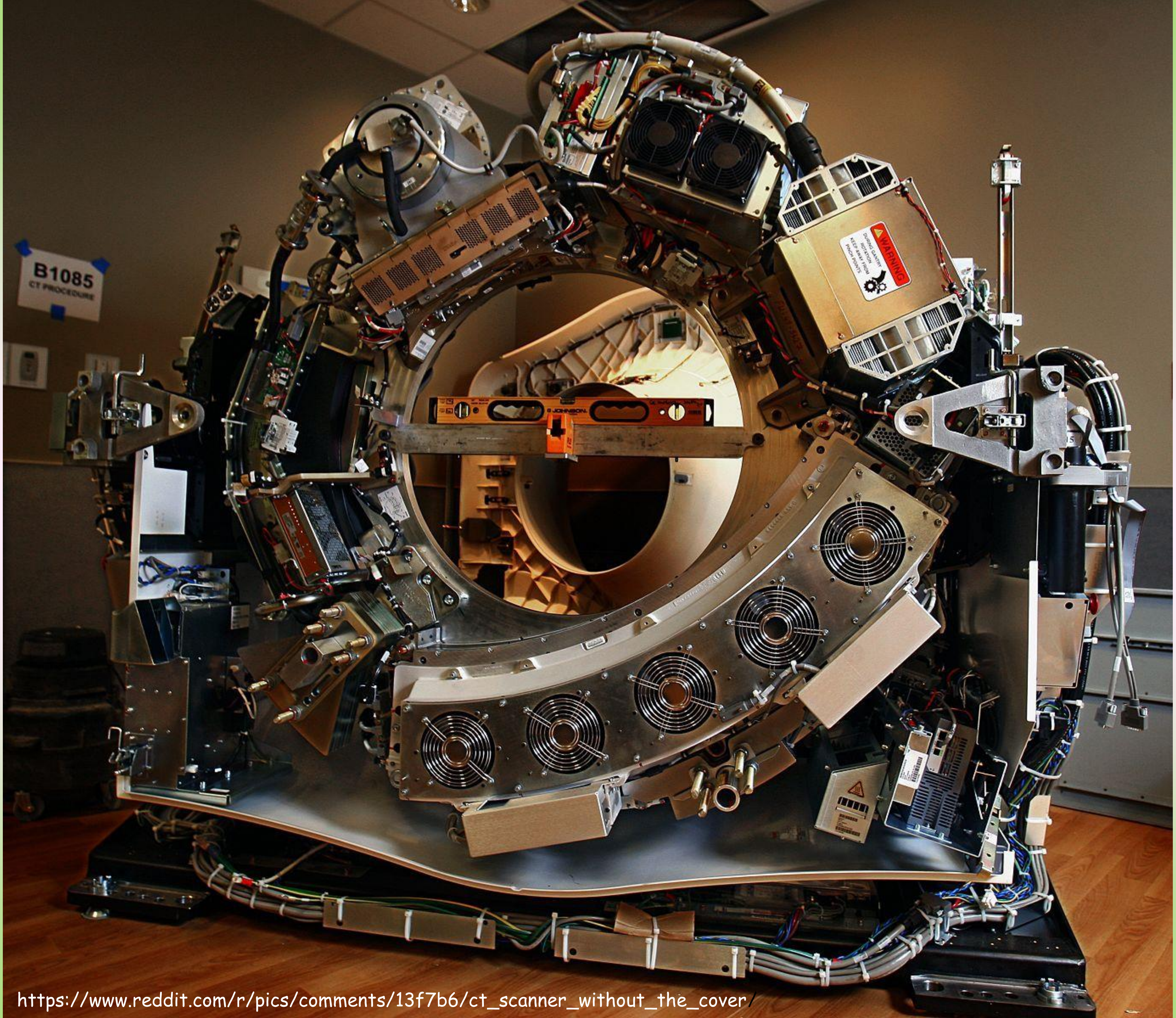
Lymphatic
Volume
Vascular
resonance
Vasculature
optical
magnetic
reveals
Microvascular
Applications
Susceptibility-based
Transport



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Students (2019/20)

- Registered:

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- Students with partial assessments in previous years?
- Are mails correct for Facebook invitation for IMAGING SYSTEMS Facebook group?

General Objectives of “Imaging Systems”

- Apresentar os conceitos aprofundados da teoria dos sistemas de formação de imagem (SI), fornecendo uma abordagem coerente aplicável à maior parte das principais áreas de aplicação.

- Compreensão dos aspectos sistémicos que apoiam as especificações básicas de um SI (resolução, sensibilidade, resposta dinâmica, funções descritivas, etc), a avaliação de desempenho e os sistemas de tolerâncias.

- Lidar com famílias de constrangimentos, requisitos operacionais, etc., no projecto de um SI e na selecção da tecnologia, incidindo sobre a arquitectura do SI e das formas de colecta de radiação (do UV ao IR), da especificação, modelação e projecto, integração e teste.

- Abordagem integrada, habituando os alunos a lidar com sistemas de requisitos e especificações, com a análise das tecnologias disponíveis ou simplesmente com considerações custo-benefício aceitáveis para o utilizador/cliente.

Contents – **theory**

- **Introduction**
  - Aspectos geométricos da formação de imagem
  - Ferramentas de projecto e de análise de sistemas
  - Conceito de *imaging chain*
  - *Overview* de aplicações e de especificidades de sistemas
- **2D Sampling**
  - Amostragem em 1D
  - Teorema de Shannon
  - Representações de dados discretos
  - Artefactos
- **Radiometry and Photometries**
  - Grandezas, unidades e principais resultados
  - Cadeia da fonte ao sensor; calibração radiométrica
  - Pupilas
- **Image Formation**
  - Representação da transmitância / reflectância de objectos 2D
  - Difracção e propagação
  - PSF e MTF
  - Função pupila generalizada
- **Systems' Architecture**
  - Formação de imagem, colecção de luz, espectroscopia
  - Com ou sem varrimento, sistemas activos e passivos
  - Adaptativos
  - Monocromáticos, hiper ou multiespectrais
  - Abertura única ou múltipla
  - Interferométricos
- **Imaging systems characterization**
  - Ruído, sensibilidade
  - Resposta tempo / frequência
  - Interfaces
- **Exemples**
  - Metrologia industrial, ambiente, astrofísica, ...

Assessment

LABORATORY– 35%

- Instrument implementation: microscopes, telescopes
- Image formation of point objects. Ideal imaging. Aberrations. Impact of stops
- Diffraction and Fourier optics. Spatial frequency spectrum. Spatial filtering
- Radiometry

PROBLEMS – 20%

- A set of ~20 problems will be made available, covering the different topics
- Students are required to deliver 10 until the last course of the semester

ESSAY– 45% (inc. Simulation) - examples

- Microscopes: STM, AFM, TEM, SEM, fluorescence, multi-photonics, ….
- Telescopes: single aperture, multiple aperture; radar telescopes, …
- Coherent or 3D imaging: interferometric imaging, OCT, SAR, holography, stereoscopy, …
- Ultrasound imaging: medical, non-destructive testing (NDT), …
- Medical imaging (non-nuclear): X-ray radiology, computerized tomography (CT), mammography, magnetic resonance imaging (MRI), …
- Nuclear medicine imaging: PET, sPET, …
- Molecular imaging (Optics & Photonics News, December 2016, p. 37)
- Remote sensing: optical, radar; radiometers, spectrometers, imagers (spectroradiometers, spectropolarimetric, imaging spectrometers, ...),
- Spectral sensing: thermal, multispectral, hyperspectral, …
- Photographic-like systems: film, video, fast photography, metrology and inspection imaging, …
- Imaging for metrology, biometry, inspection, surveillance, autonomous navigation, human-computer interface (HCI), …
- Light field imaging: Lytro-like (focus after shooting), …
- Virtual / extended / augmented reality systems (Lumus, ...)
- Security imaging : hidden and scrambled / phase modulation (van Renesse, ...)
- Special support technologies for imaging: imaging sensors, adaptive optics, TDI sensors, scanning systems, stabilization, superresolution, increasing FOV techniques (stacking & stitching) …

PARTICIPATION – 0%

- Individual short presentations on interesting topics (15 minutes each)
- Attendance of >= 80% of classes

Assessment detailed explanation

File available on
Fénix & Facebook

Ciências ULisboa

INTEGRATED MASTER IN PHYSICAL ENGINEERING (MIEF)

IMAGING SYSTEMS (2019/20)

ASSESSMENT

José Manuel Rebordão, João Pinto Coelho

Revised: 13-9-2019

The goal of **IMAGING SYSTEMS** is not applications *per se*, but the architecture of IMAGING SYSTEMS, their enabling technologies and the most relevant system properties: resolution, dynamics and sensitivity.
Key concepts: 1. Imaging, 2. Systems

I – Components of the Assessment

LABORATORY – 35%

- Instrument implementation: microscopes, telescopes
- Image formation of point objects. Ideal imaging. Aberrations. Impact of stops
- Diffraction and Fourier optics. Spatial frequency spectrum. Spatial filtering
- Radiometry

PROBLEMS – 15%

- A set of 20 problems will be made available
- Students are required to deliver half (10) until the last course

ESSAY – 40% (inc. Simulation) – examples

- [illegible]
- Telescopes: [illegible]
- [illegible]
- [illegible]
- Medical imaging [illegible]
- Nuclear medicine imaging: [illegible]
- Molecular imaging ([illegible])
- Remote sensing: optical, radar, [illegible]
- Spectral imaging: thermal, multispectral, hyperspectral, …
- Photographic [illegible]
- Imaging for [illegible]
- Light field imaging: [illegible]
- [illegible]
- [illegible]
- [illegible]

PARTICIPATION – 10%

- Individual short presentations on interesting topics (15 minutes each)
- Attendance of >= 80% of classes

Relative weights may change by +/- 5%.

II – Laboratory reports

The aim of the laboratory reports is to objectively describe each of the experiments carried out, identifying the materials and methods used, the schematic and functional representation of the experimental setup and the results, according to what is requested in the work plan - which will be distributed in advance.

For a better understanding of each work, the following guidelines should be followed when writing the reports:

1. Brief introduction to the subject, with the theory and mathematics relevant to the analysis of the results
2. Explanation of methods and materials / systems used
3. Overview of the results and suitable analysis (in relation to the underlying theory)
4. Conclusions, well supported by the analysis
5. References or bibliography identified
6. Activities common to several experiments (e.g. characterization of the lenses used) should be addressed in annexes

Evaluation will also address:

- The language used and quality of the information
- Critical thinking and clear separation between observations and interpretations (based on theory or explanatory hypotheses).

Experiments may be carried out in groups of 2-3 students, at most, with a common laboratory report. The participation of each student in the experiments will be taken in consideration.

Essays – Imaging **Systems** case studies – pick one!

- Microscopes: STM, AFM, TEM, SEM, fluorescence, multi-photonics, ….
- Telescopes: single aperture, multiple aperture; radar telescopes, …
- Coherent: interferometric imaging, VLBI, OCT, SAR (remote sensing), …
- 3D Imaging: holography (coherent), stereoscopy, ranging (lidar)…
- Ultrasound imaging: ecographies (& Doppler), non-destructive testing (NDT), …
- Medical imaging (non-nuclear): X-ray radiology, computerized tomography (CT), mammography, magnetic resonance imaging (MRI), …
- Nuclear medicine imaging: PET, sPET, …
- Molecular imaging (Optics & Photonics News, December 2016, p. 37)
- Remote sensing: optical, radar; radiometers, spectrometers, imagers (spectroradiometers, spectropolarimetric, imaging spectrometers, ...),
- Spectral sensing: thermal, multispectral, hyperspectral, …
- Photographic-like systems: film, video, fast photography,
- Security imaging : hidden and scrambled / phase modulation (van Renesse, ...)
- Light field imaging: Lytro-like (focus after shooting), …
- Special **Technologies** for Imaging:
  - Imaging sensors
  - Adaptive optics
  - TDI sensors
  - Scanning systems
  - Stabilization
  - Superresolution

Bibliography (examples) → LISTA (Excel)

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CVonline: The Evolving, Distributed, Non-Proprietary, On-Line Compendium of Computer Vision

http://homepages.inf.ed.ac.uk/rbf/CVonline/

Computer Vision O.N.L.I.N.E

http://www.computervisiononline.com/software

Bibliography (examples) – LISTA (Excel)

https://www.dropbox.com/sh/j7j6lb1grink9zy/AACvCqSjPceF7Rm-TbJT8z6Ja?dl=0

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3	Amidror I, The Theory of the Moiré, Phenomenon (Springer, 2009)	Springer	2009
4	Bajorski P, Statistics for Imaging, Optics, and Photonics (Wiley, 2011)	Wiley	2011
5	Barter J., Telescopes (Gale, 2005)	Gale	2005
6	Bass M et al, Handbook of Optics, Volume I - Geometrical and Physical Optics, Polarized Light, Components and Instruments (2009)		2009
7	Bass M et al, Handbook of Optics, Volume II - Design, Fabrication and Testing, Sources and Detectors, Radiometry and Photometry (2009)		2009
8	Bass M et al, Handbook of Optics, Volume III - Vision and Vision Optics (McGraw-Hill, 2009)	McGraw-Hill	2009
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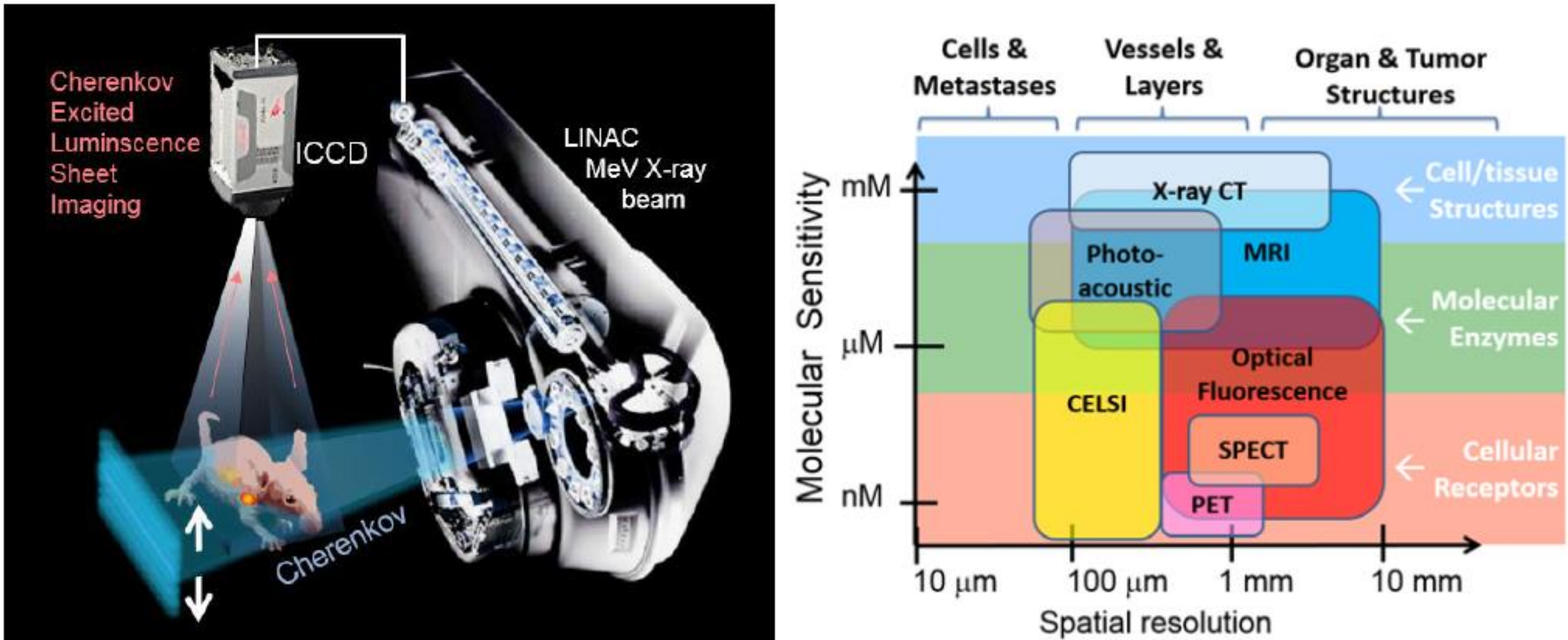
Molecular imaging

(Optics & Photonics News, December 2016, p. 37)



(Left) CELSI imaging uses a linear accelerator (LINAC) beam, shaped to sheet-illuminate a rodent with Cherenkov radiation. Gated luminescence from the animal is imaged from above using an intensified CCD (ICCD) camera. (Right) The imaging approach fills a niche in the molecular-imaging world, with the highest spatial resolution (100–300 microns) and molecular sensitivity (micromolar to nanomolar), and works for biologically compatible organic molecules.

RESEARCHER

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CELSI - Cherenkov excited-luminescence sheet imaging

The Computer Vision Industry (David Lowe, 2015)

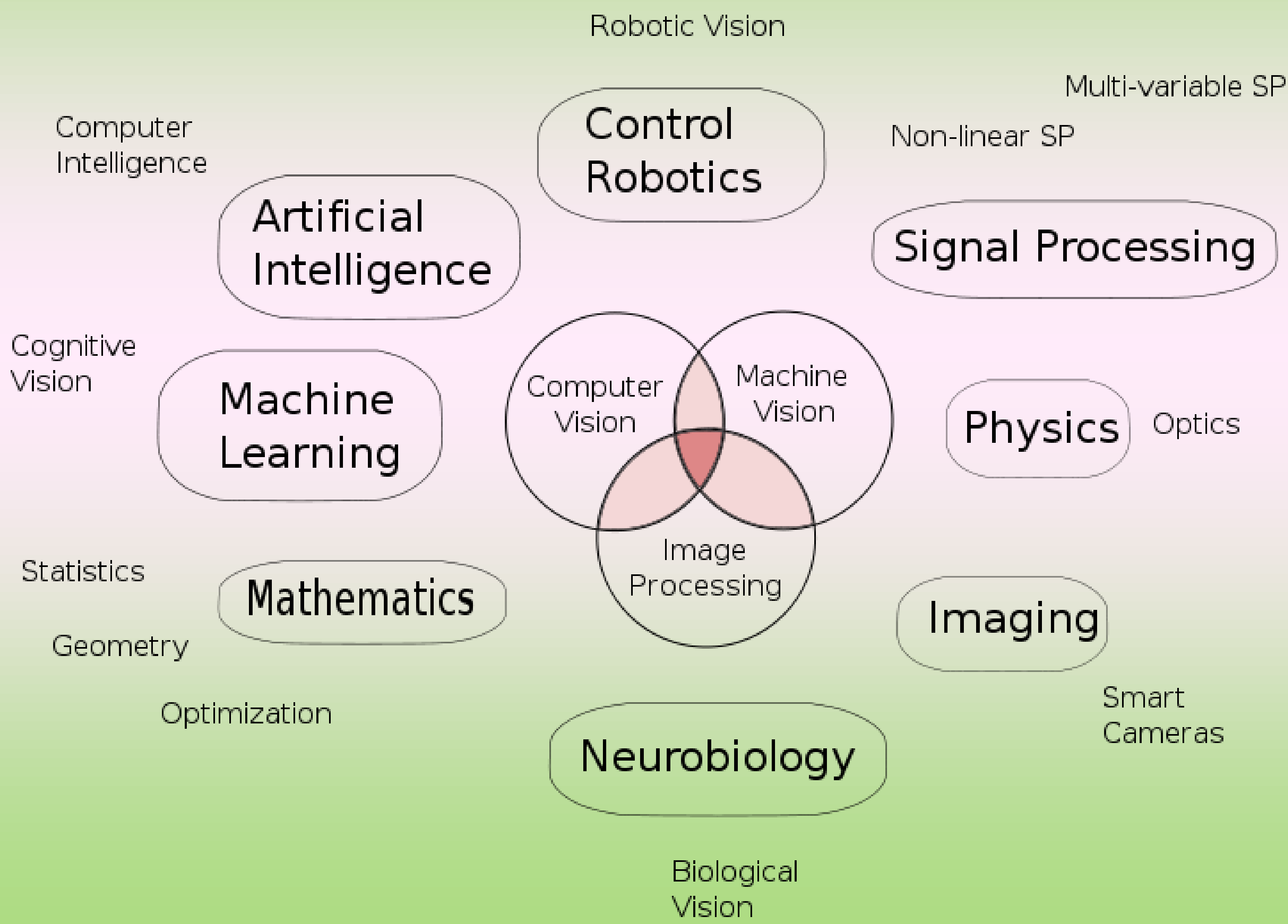
- Automobile driver assistance & traffic and road management
- Eye and Head Tracking
- Film and Video
- Sports analysis
- Gesture Recognition
- General purpose vision systems
- Industrial automation and inspection
  - Electronics industry
  - Food and agriculture
  - Printing and textiles
  - Other
- Medical and biomedical
- Object Recognition and Augmented Reality for Mobile Devices
- Photography
- People tracking
- Safety monitoring
- Security:
  - Biometrics
  - Monitoring and Surveillance
- 3D modeling
- Web and Cloud Applications

Relation between computer vision and various other fields

"If We Want Machines to Think, We Need to Teach Them to See"

(http://en.wikipedia.org/wiki/Computer_vision

(http://www.kdnuggets.com/2016/08/seven-steps-understanding-computer-vision.html)



Imaging instruments / systems are used for:

- Mapping (2D or 3D fields)
- Meteorology
- Medical & biomedical
- Metrology
- Inspection
- Microscop(y)(ies)
  - Optical
    - Visible, UV, IR, ...
  - Electron
  - Scanning probe (STM, AFM)
  - Superresolution
  - ...
- Astronomy
- Security
- Biometrics
- Photography
- Video
- Film
- Military
- Security and surveillance
- Vision enabling / emulators in (semi)automatic systems
- Probing
- Light concentration

Imaging systems can be:

- Active / passive
- Static / scanning
- Monolithic / multi-aperture / interferometric imaging
- Monochromatic / multispectral / hyperspectral (frequency range)
- Intensity / phase (coherency) / polarization / wavelength sensitive
- 2D or 3D
- Imaging / non-imaging
- Radiometers, spectrometers, imagers (spectro-radiometers, imaging spectrometers, ...)
- Superresolution

Imaging systems are characterized in terms of:

- **Intrinsic parameters**
  - Resolution (PSF, MTF)
  - Sensitivity
  - Dynamic range
  - Field of view (FOV) / Field of regard (FOR)
  - Depth of focus
  - Space-variant / space invariant properties (aberrations)
  - Sampling (spatial / dynamic / temporal)
  - ...
- **Operational parameters**
  - Quantization
  - Rates (pixel, frames, ...)
  - Integration time control
  - Noise reduction mechanisms
  - Stabilization
  - Signal handling and interfaces
  - Signal & image processing (on-chip, external)
  - Reconstruction techniques
  - Coding / compression
  - ...

Photonics

***"Photonics is the science of the harnessing of light.** Photonics encompasses the generation of light, the detection of light, the management of light through guidance, manipulation, and amplification, and most importantly, its utilisation for the benefit of mankind."*

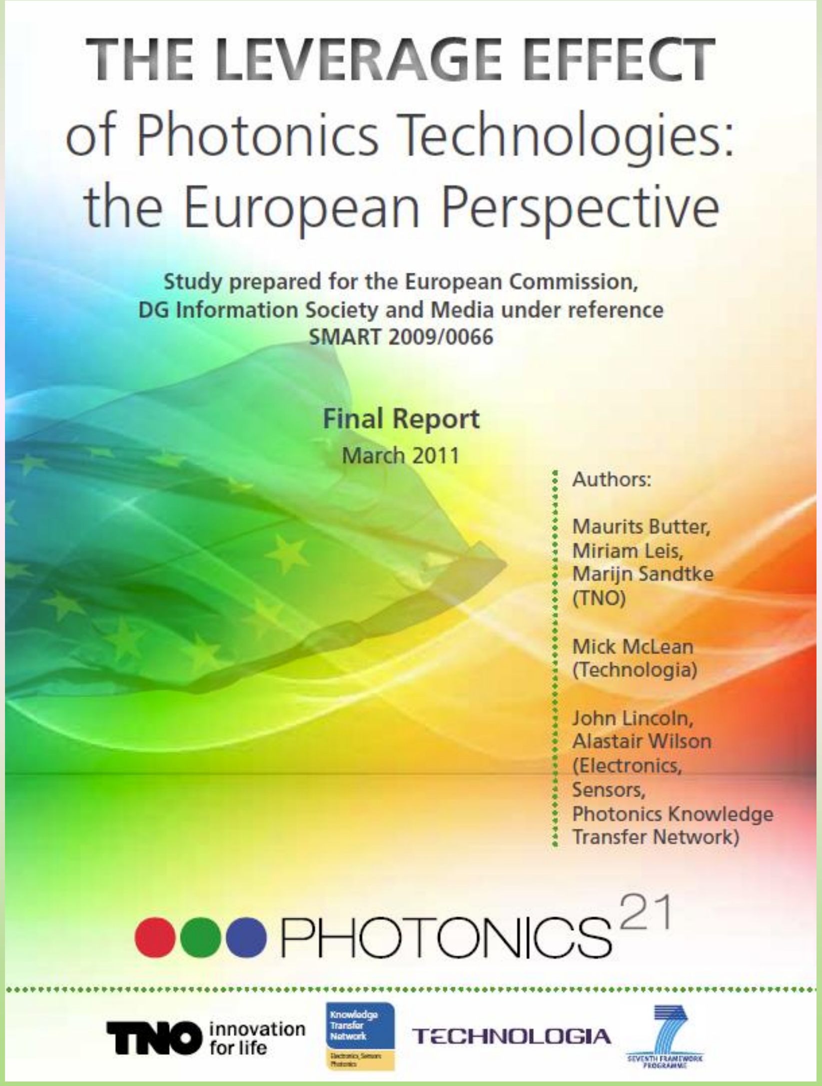
Photonics is an area of study that involves the use of radiant energy (such as light), whose fundamental element is the **photon** . Photonic applications use the photon in the same way that electronic applications use the electron. Among the large number of current or possible photonic applications are: photonic switching, photonic networks, the photonic computer.

Photonics is one of the fastest growing **high-tech industries** in the world today. It includes:

- optical communications (e.g., fiber optics, lasers, and infrared links),
- **optical imaging (e.g., spy and weather satellites, night vision, holography, flat screen display, and CCD video cameras),**
- optical data storage and optical computing (e.g., CD's and DVD's),
- optical detectors (e.g., supermarket scanners, medical optics, and nondestructive evaluation of materials),
- lasers (e.g., welding lasers, laser surgery, laser shows, and laser rangefinders)
  spectroscopy (e.g., chemical and biological detection, anti-terror detection)
- quantum optics (e.g., quantum teleportation, quantum cryptography, and single-photon optics)

Photonics21 - http://www.photonics21.org

"Photonics is the science of the harnessing of light. *Photonics encompasses the generation of light, the detection of light, the management of light through guidance, manipulation, and amplification, and most importantly, its utilisation for the benefit of mankind."*



Readiness Levels

- **Technology Readiness Levels**
  - NASA (1995), DoD, …, H2020
  - https://en.wikipedia.org/wiki/Technology_readiness_level
  - https://www.nasa.gov/pdf/458490main_TRL_Definitions.pdf
  - https://esto.nasa.gov/files/TRL_definitions.pdf

- **System Readiness / Maturity Levels**

Technology Readiness Levels (TRLs): Overview

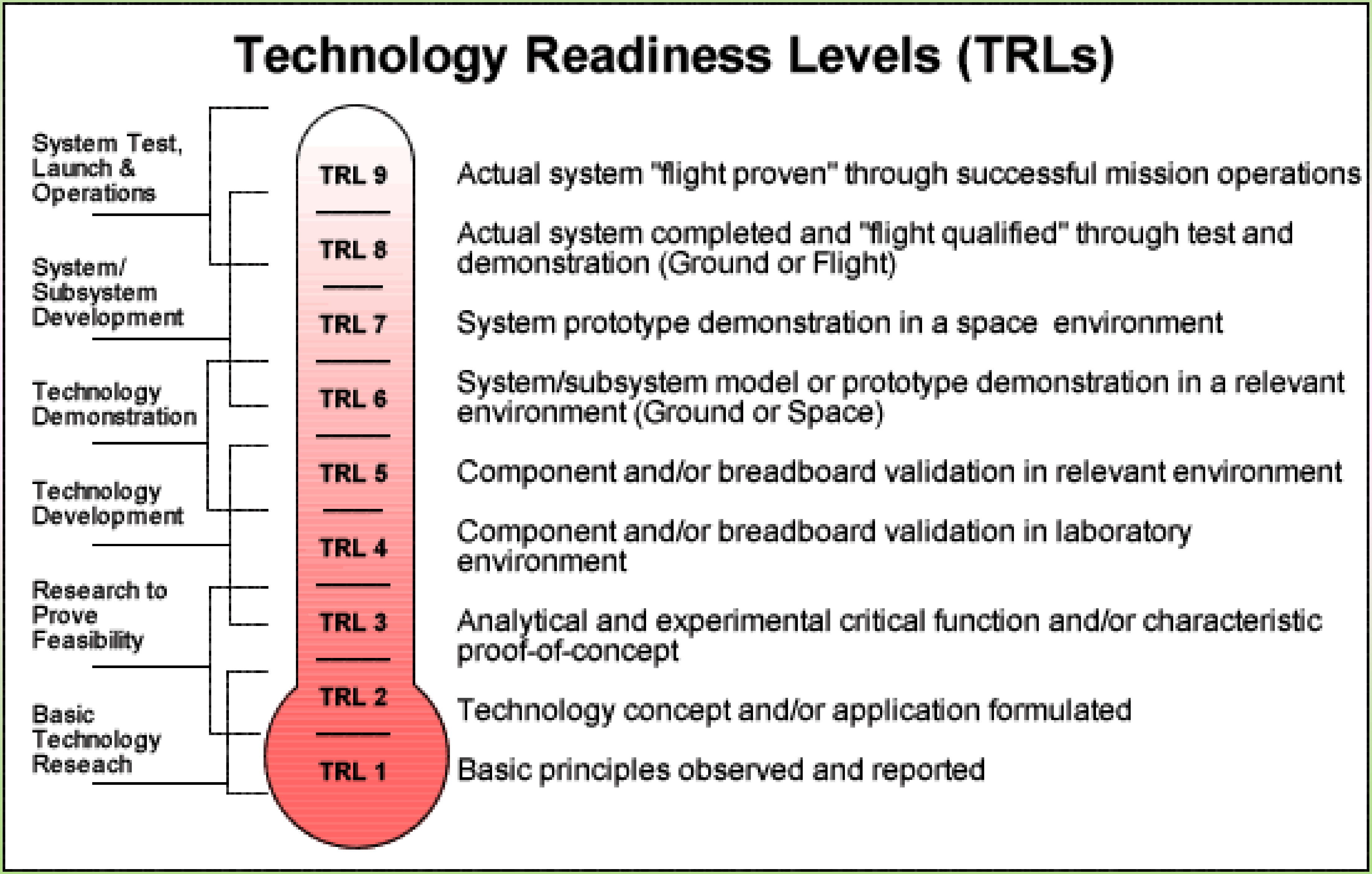
TRLs are NASA-generated and Used Extensively by DoD

Basic principles observed and reported	1	Basic
Technology concept and/or application formulated	2	
Analytical and experimental critical function and/or characteristic	3	
Component and/or breadboard validation in laboratory environment	4	Advanced
Component and/or breadboard validation in relevant environment	5	
System/subsystem model or prototype demonstration in a relevant environment	6	Applied
System prototype demonstration in a operational environment	7	
Actual system completed and 'flight qualified' through test and demonstration	8	
Actual system 'flight proven' through successful mission operations	9	

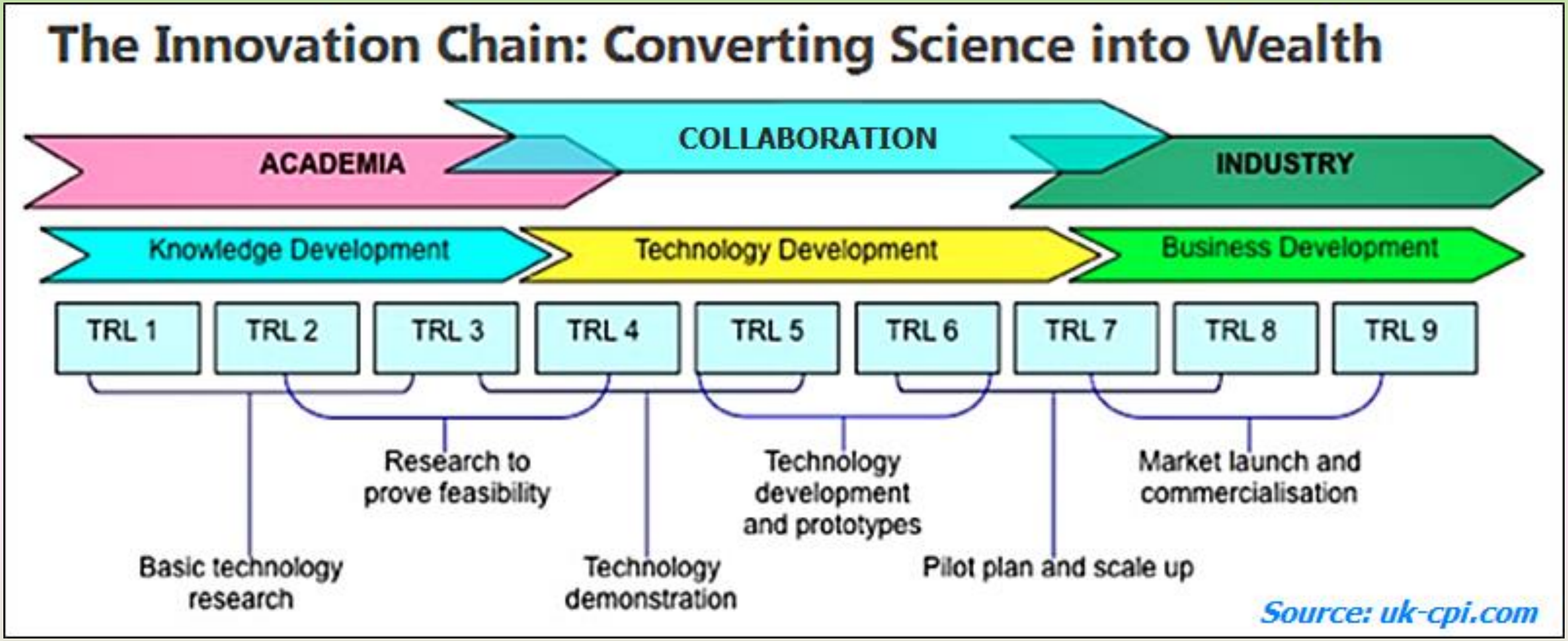
TRL

TRL	**9**	Commercialized
	8	Pre-production
	7	Field Test
	6	Prototype
	5	Bench / Lab Testing
	4	Detailed Design
	3	Preliminary Design
	2	Conceptual Design
	1	Basic Concept

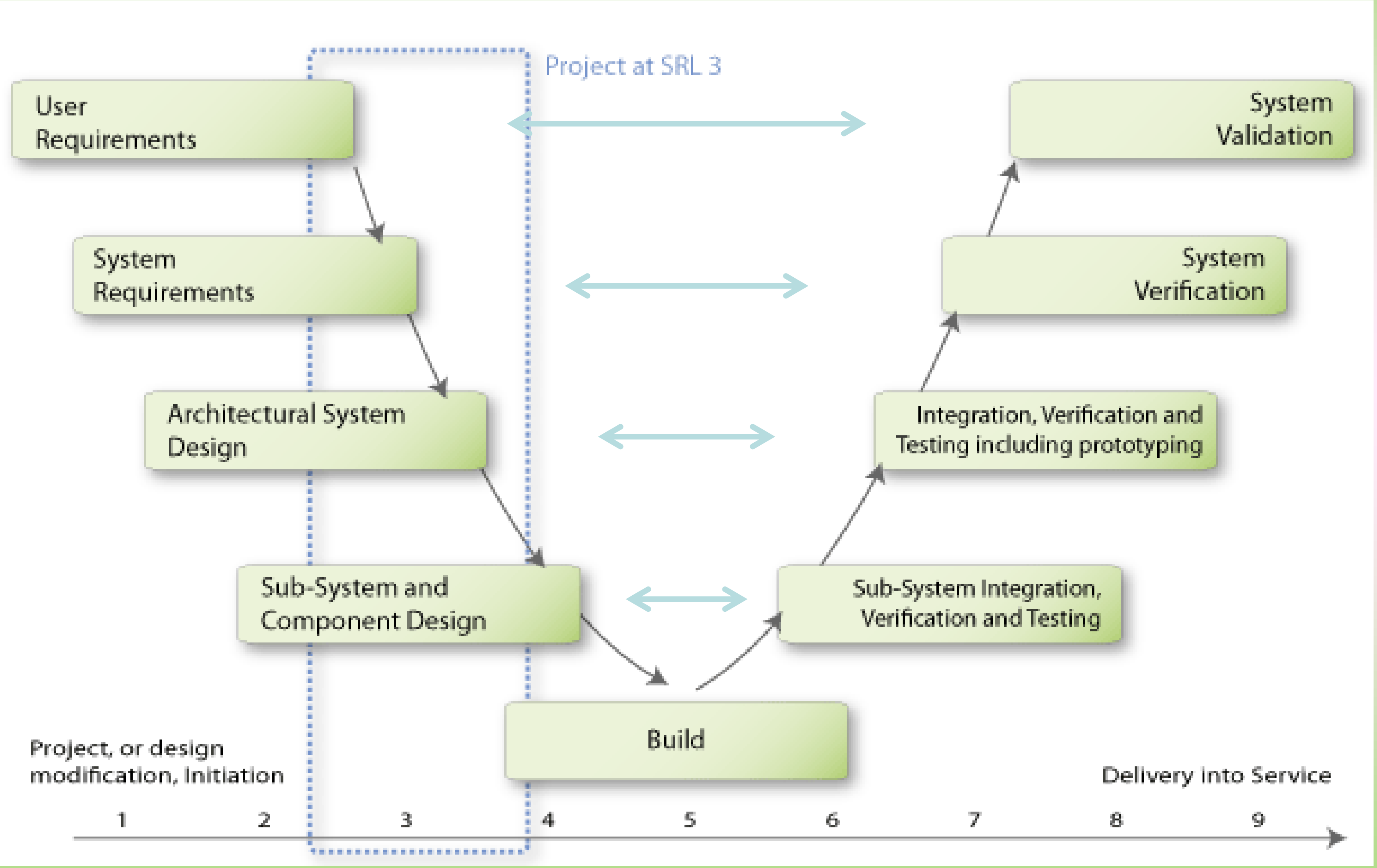
TRL – Technological Readiness Levels



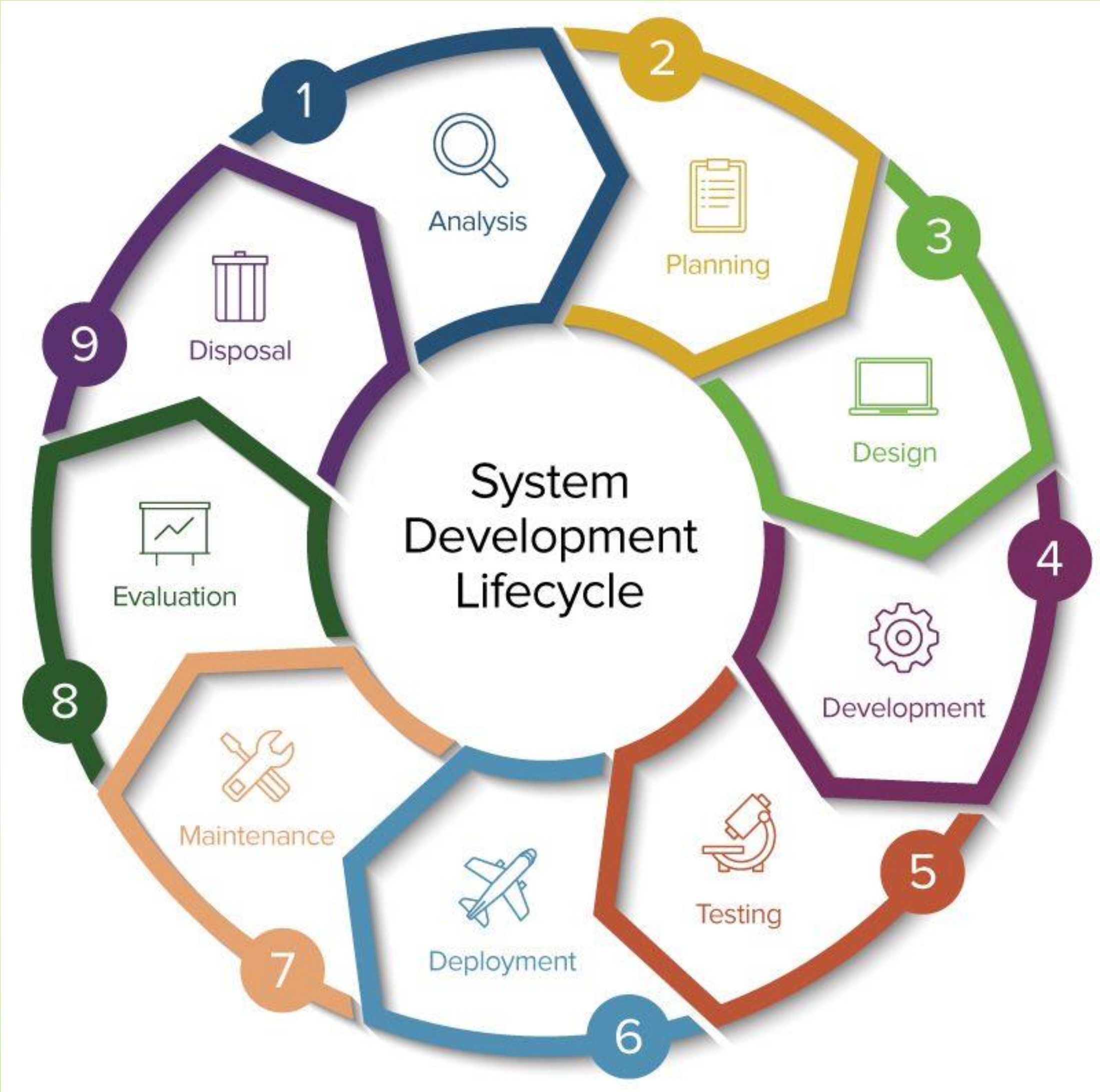
Innovation chain



System Readiness / Maturity Levels



System development cycle



https://www.smartsheet.com/system-development-life-cycle-guide

Systems @ Edu (MIEF) level

I – PHYSICS FUNDAMENTALS

II – ENABLING TECHNOLOGIES

III – SYSTEM CONCEPTS

IV – APPLICATIONS / MARKETS

PHYSICS
CHEMISTRY
BIOLOGY
IT
MEDICAL
SOCIAL SCIENCES

REGULATIONS
PUBLIC POLICIES
PRIVACY
HUMAN RIGHTS
…