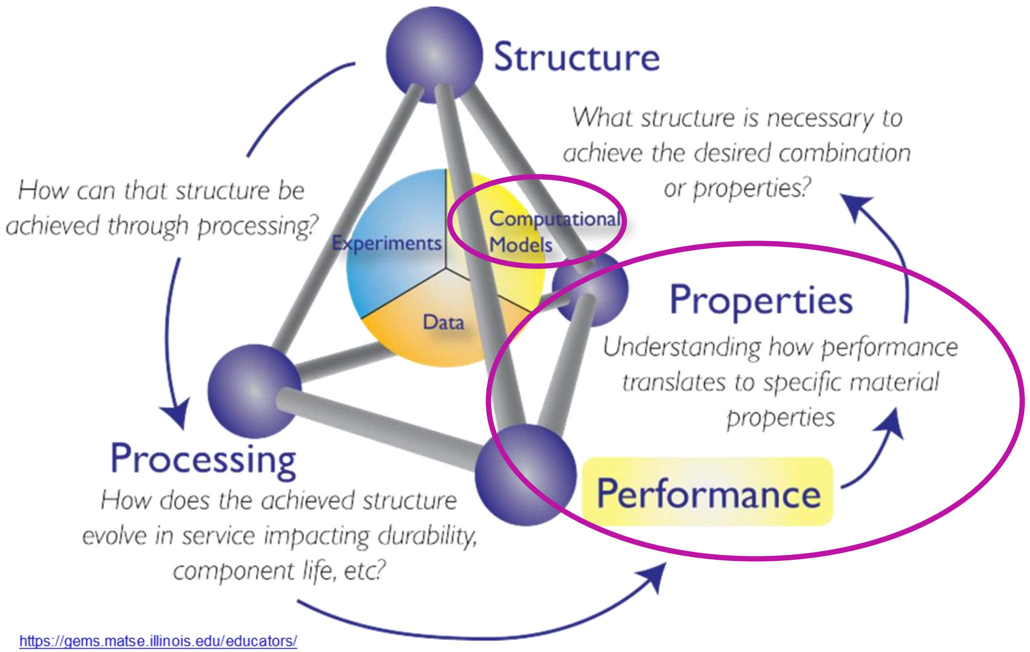
Aalto University
School of Engineering

COE-C2004 - Materials Science and Engineering

Exercise 5

Prof. Junhe Lian
Zinan Li

GRANTA overview



https://gems.matse.illinois.edu/educators/

GRANTA EduPack

Overview: Materials and process selection tool

Basic Features:

- Look up information
- Create Charts
- Select materials or processes
- Assess design by Eco Audit

Features unique to Granta EduPack:

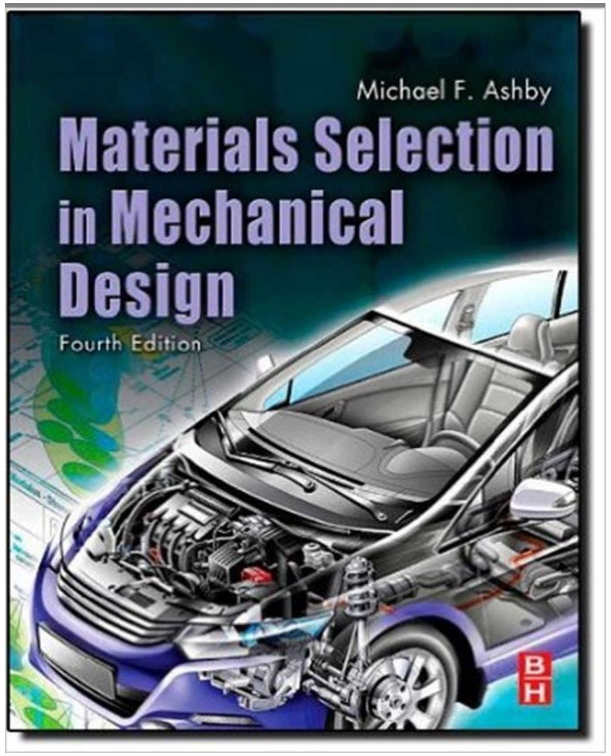
- Level Structure
- Science Notes
- Video Tutorials
- Online teaching resources

https://www.ansys.com/products/materials/granta-edupack/

Textbook and software

Textbook

Ashby, Michael F.
Materials Selection in Mechanical Design
(Chapter 3, 5 and 7).



Software

GRANTA EduPack
(was Cambridge Engineering Selector,
from Granta Design Software, now part of ANSYS)

Tasks

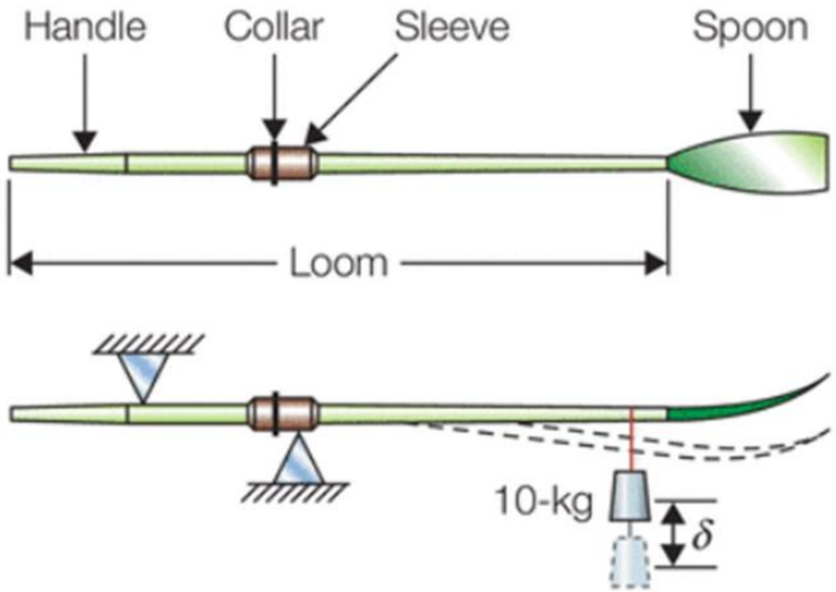
Aalto University
School of Engineering

Example task

Material selection for Oars

A beam as light as possible and strong enough to carry, without breaking the bending moment exerted by the person, i.e., the stiffness must be met

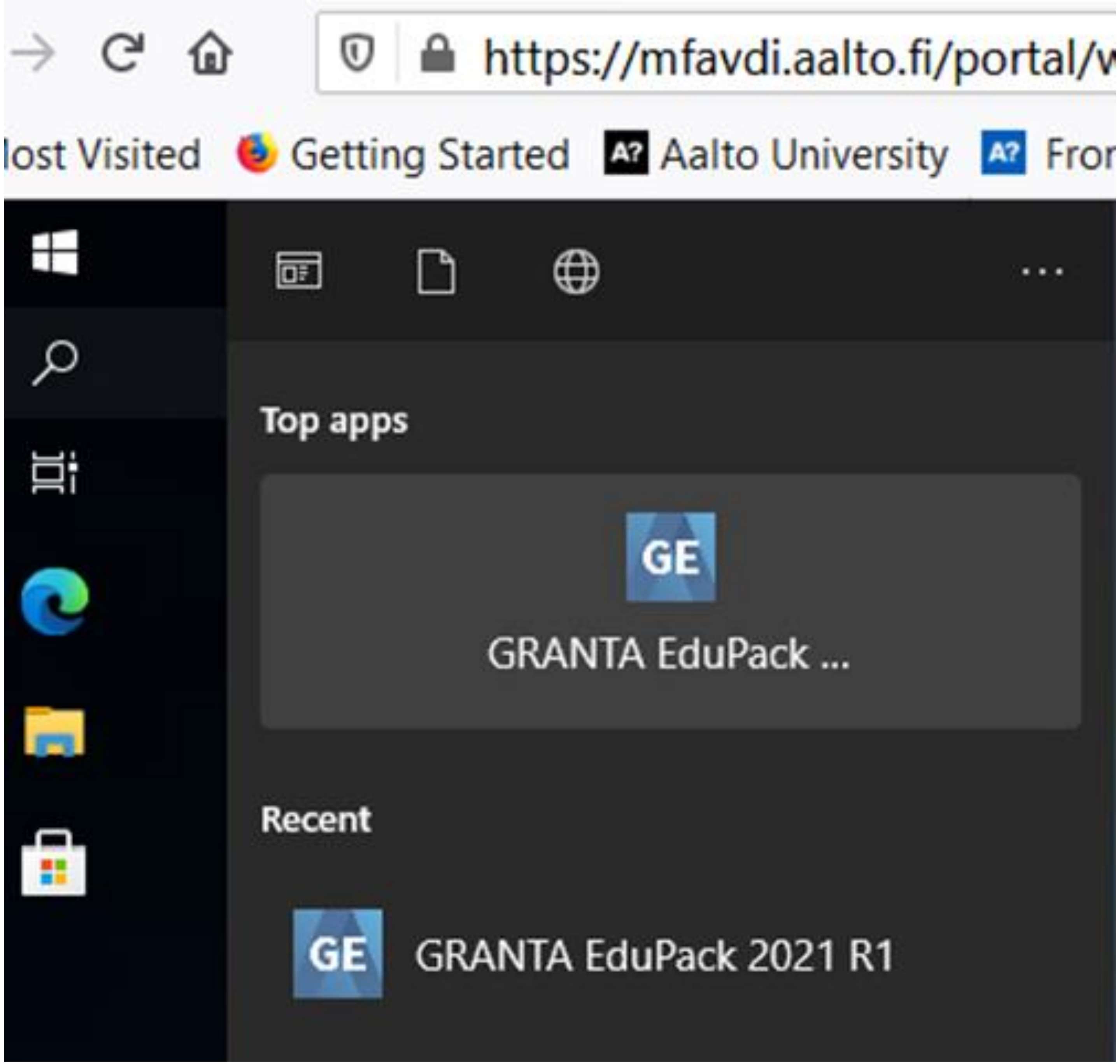
- Derive the formula for the material performance index from the performance objective
- Draw the material selection maps with density and Young's modulus as axes



GRANTA operations

Access to the software

Local installation and VDI connection



Access to GRANTA EduPack
Method 1 – Local Software Installation

Step 1. Check system requirements.

GRANTA EduPack is designed for computers running Windows. To install GRANTA EduPack, you will need the following:

- A compatible Microsoft® Windows® operating system;
    - Windows 8 32-bit or 64-bit,
    - Windows 10 32-bit or 64-bit.
- 4 GB of RAM, 4 GB of available hard disk space.
- Microsoft .NET Framework version 4.6.2, Microsoft Report Viewer 2010 SP1, and Microsoft VC 141 redistributable.
    - If any of these are not installed, they will be installed during the GRANTA EduPack installation. You may need to restart your computer and the installer. You may need to restart your computer. If you restart your computer, you will have to restart the installer, too.
    - For the French, German, and Spanish language installations, you will also require the appropriate language packs for these, which are usually installed with your OS.
- Administrator rights and Internet access.

For macOS or Linux users, the following two options should be considered (both require you to have a licensed version of Windows):

- Boot Camp—Boot Camp is software that comes installed with macOS (compatible with macOS 10.6 or later) that allows you to run compatible versions of Microsoft Windows on an Intel-based Mac. As Boot Camp runs the Windows operating system directly, the performance of Windows applications is not affected. The downsides of using Boot Camp are the risks involved with re-partitioning the hard drive and the need to boot into Windows each time you wish to use GRANTA EduPack.
- Install Windows on a virtual machine on your Mac. This allows you to run Windows software, including GRANTA EduPack, from inside macOS as if it were installed on your Mac.

Step 2. Download software copy from Aalto download service.

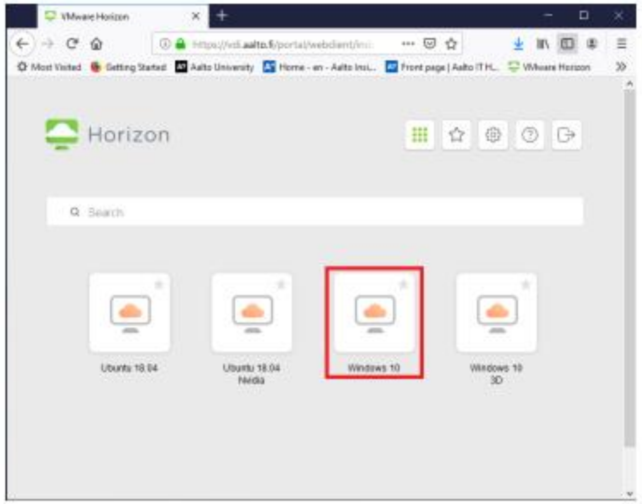
- visit Download.aalto.fi;

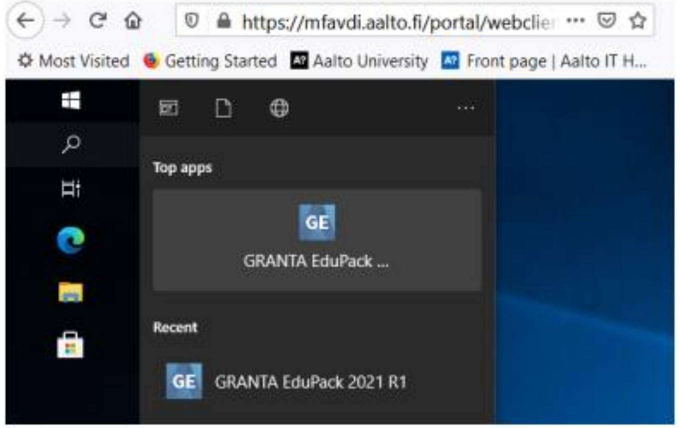
NOTE: Aalto user credentials log in is needed – YOU NEED TO LOGIN TO AALTO VPN FIRST

Access to GRANTA EduPack
Method 2 – Lauch Application via Remote Access

Alternatively, you can get access remotely to the Windows classroom computers from your own device, using the VDI system via VMware Horizon Client vdi.aalto.fi or mfavdi.aalto.fi (Aalto user credentials log in is required). Check Remote access to Windows classroom computers for more information.

- GRANTA EduPack 2021 R1 application is available on virtual computer "Windows 10" on vdi.aalto.fi;





GRANTA EduPack 2021R1

quick start   what's new   add database   extra databases

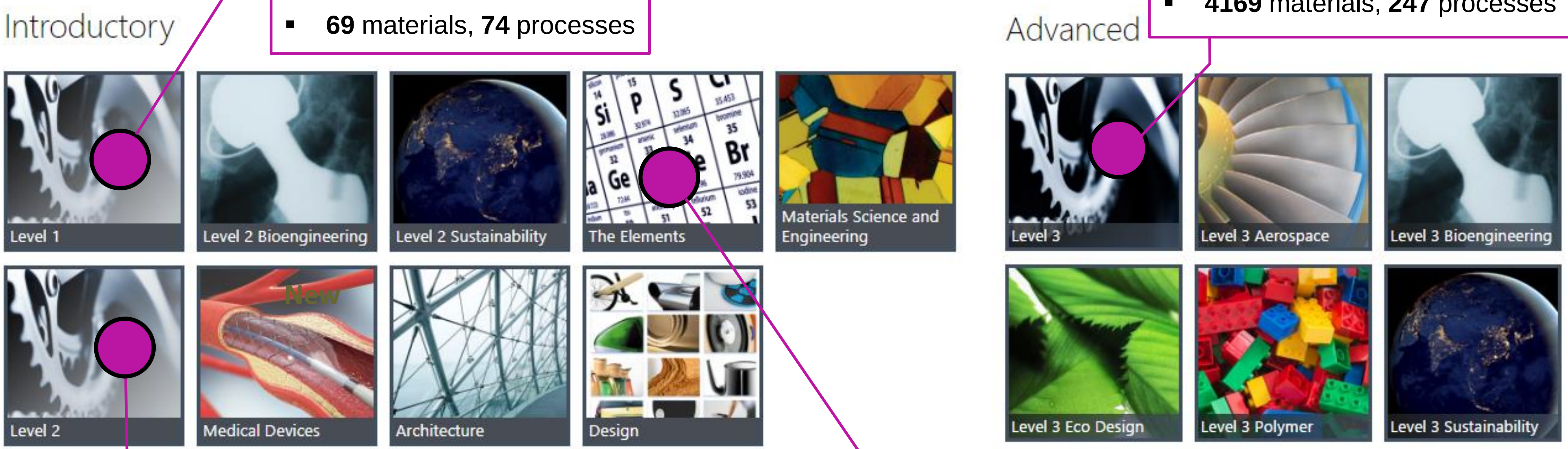
Databases

Level 1, general

- Schools, **1st year** college
- **69** materials, **74** processes

Level 3, general

- **3rd-4th year**, **masters** and **research**
- **4169** materials, **247** processes



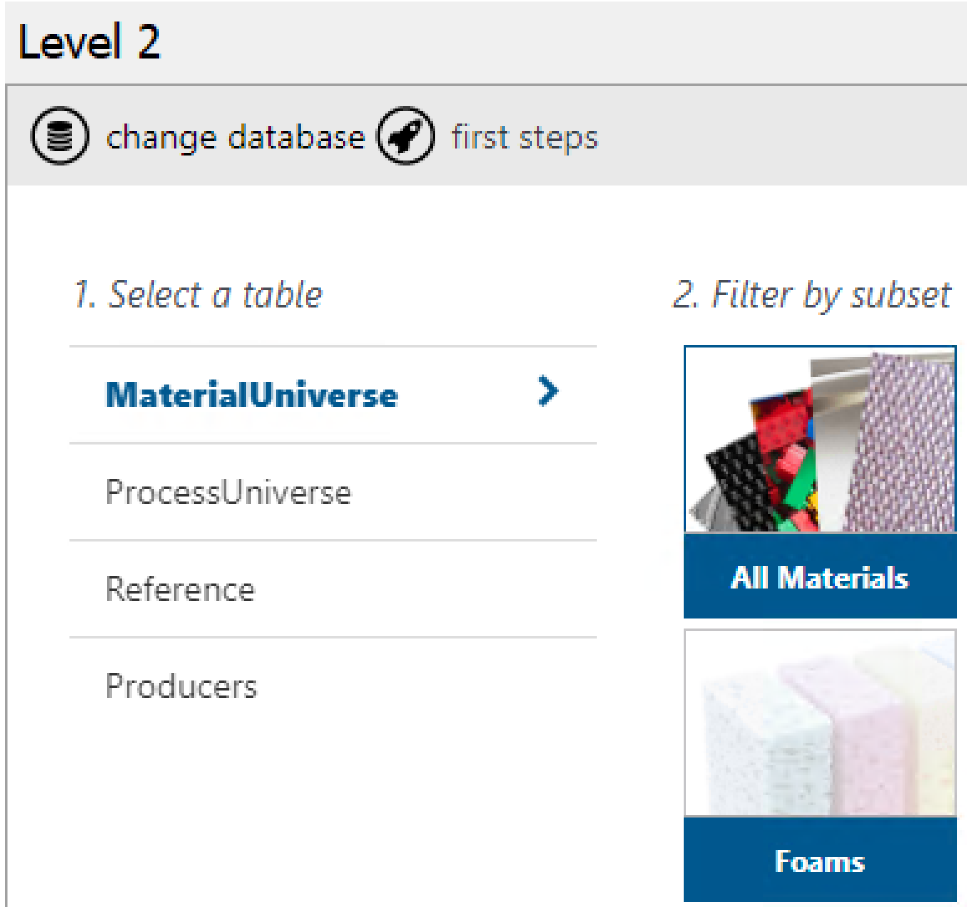
Level 2, general

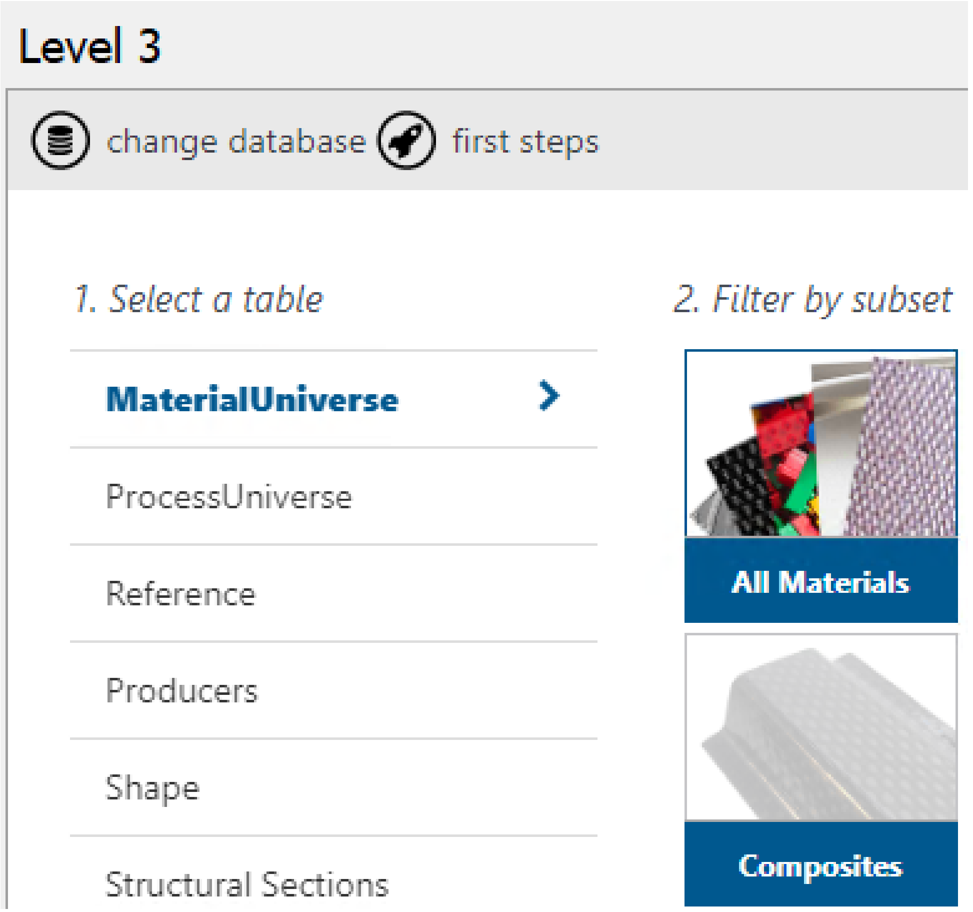
- **1st-3rd year** students of Engineering, Materials Science and Design
- **100** materials, **116** processes

The Elements Database

- Schools-University students
- **149** records, periodic table

Changing database - different levels





Intuitive navigation

File Edit View Select Tools Window Feature Request Help

Home | Browse | Search | Chart/Select | Solver | Eco Audit | Synthesizer | Learn | Tools | Settings | Help

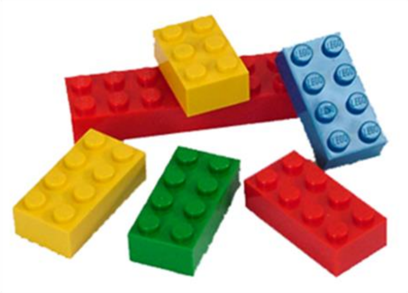
Table: *MaterialUniverse*

Subset: *All materials*

- MaterialUniverse
  - Ceramics and glasses
  - Hybrids: composites, foams,
  - Metals and alloys
  - Polymers and elastomers

Acrylonitrile-butadiene-styrene (ABS)

The material. ABS (Acrylonitrile-butadiene-styrene) is tough, resilient, and easily molded. It is usually opaque, although some grades can now be transparent, and it can be given vivid colors. ABS-PVC alloys are tougher than standard ABS and, in self-extinguishing grades, are used for the casings of power tools.



General properties

Density	1.01e3	-	1.21e3	kg/m^3
Price	* 2.5	-	3	USD/kg
Date first used				1937

Mechanical properties

Young's modulus	1.1	-	2.9	GPa
Yield strength	18.5	-	51	MPa
Tensile strength (elastic limit)	27.6	-	55.2	MPa
Elongation	1.5	-	100	% strain
Hardness - Vickers	5.6	-	15.3	HV
Fatigue strength at 10^7 cycles	11	-	22.1	MPa
Fracture toughness	1.19	-	4.29	$MPa.m^{1/2}$

and...

Thermal properties

Electrical properties

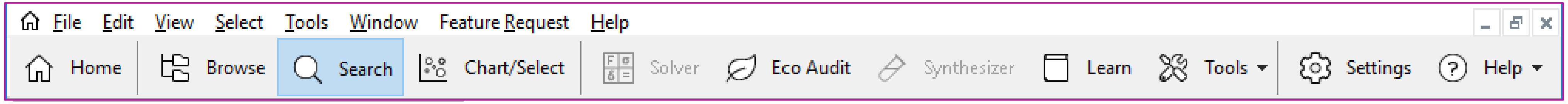
Optical properties

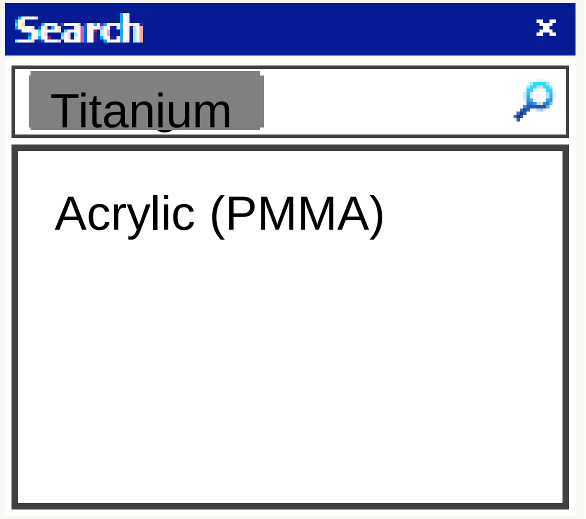
Processability

Eco properties etc.

Links to Processes

The Search function





- Not sensitive to CASE but to spelling
- Searches all data-tables
- Operators AND, OR, NOT, * …
- Categorizes all results
- Highlights search term in datasheet

Polymethyl methacrylate (Acrylic, PMMA)

The material. When you think of PMMA, think transparency. Acrylic, or PMMA, is the thermoplastic that most closely resembles glass in transparency and resistance to weathering. The material has a long history: discovered in 1872, first commercialized in 1933, its first major application was as cockpit canopies for fighter aircraft during the second World War.

Caption Car rear light casing. © Chris Lefteri

Compositional summary

(CH2-C(CH3)COOCH3)n

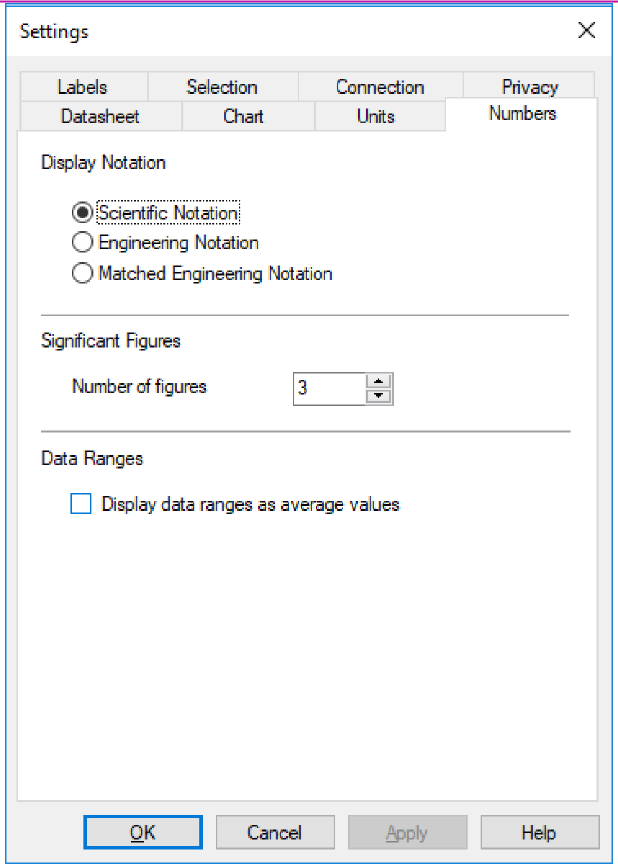
General properties

Density	1.16e3	-	1.22e3	kg/m^3
Price	* 3.14	-	3.74	USD/kg
Date first used				1933

Mechanical properties

Young's modulus	2.24	-	3.8	GPa
Yield strength (elastic limit)	53.8	-	72.4	MPa
Tensile strength	48.3	-	79.6	MPa
Elongation	2	-	10	% strain
Hardness - Vickers	16.1	-	21.9	HV
Fatigue strength at 10^7 cycles	* 15.2	-	32.7	MPa

Changing the data settings (units etc.)



Accessing the science behind the properties

Acrylonitrile-bu

The material. ABS (Acrylonitrile-buta
tough, resilient, and easily molded. It is
although some grades can now be tran
be given vivid colors. ABS-PVC alloys
standard ABS and, in self-extinguishing
for the casings of power tools.

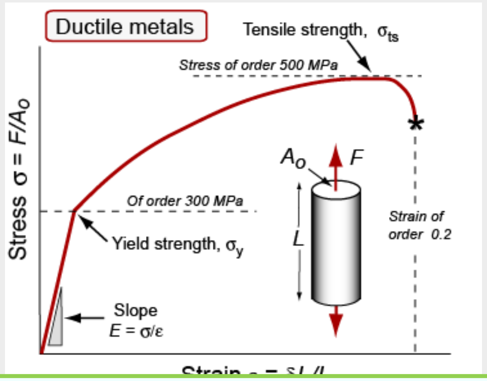
General properties

Density	1.01e3	-
Price	* 2.5	-
Date first used		

Mechanical properties

Young's modulus	1.1	-
Yield strength	18.5	-
Tensile strength (elastic limit)	27.6	-
Elongation	1.5	-
Hardness - Vickers	5.6	-
Fatigue strength at 10^7 cycles	11	-
Fracture toughness	1.19	-

Young's modulus



Definitions and measurement. Figure 1 shows a typical tensile stress-strain curve. The initial part is linear (Hooke's law), and it is elastic, meaning that the strain is recoverable – the material returns to its original shape when the stress is removed. Stresses above the elastic limit cause permanent deformation or fracture

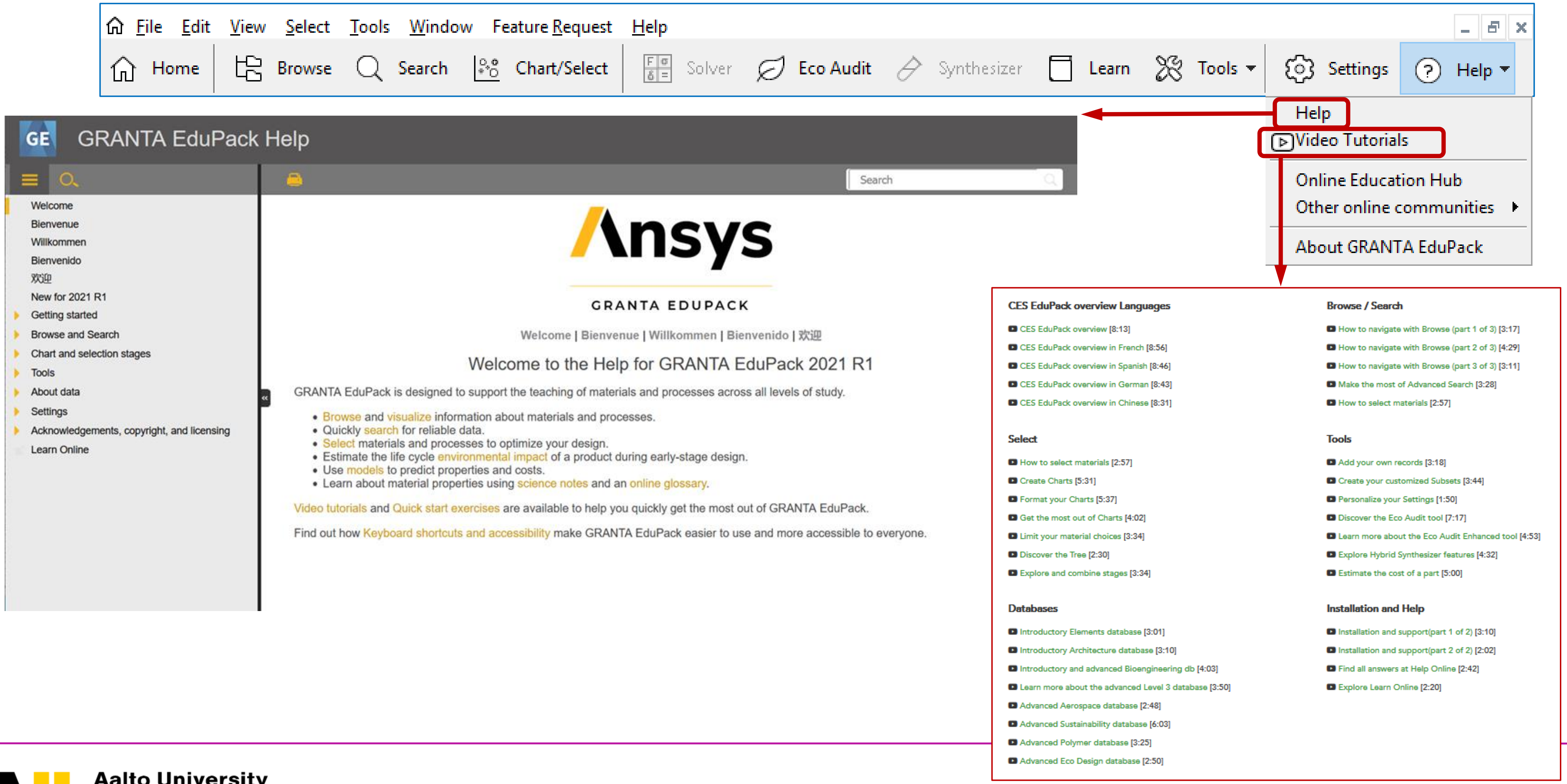
………

The origins of moduli. Atoms
together, some weakly, some strong
bind strongly enough they form solic
stronger the bond, the higher is the
point of the solid. Think of the bond
springs (Figure 3). The atoms have
equilibrium spacing ; a force pulls t
a little, to , but when it is released th
back to their original spacing.

. ……….

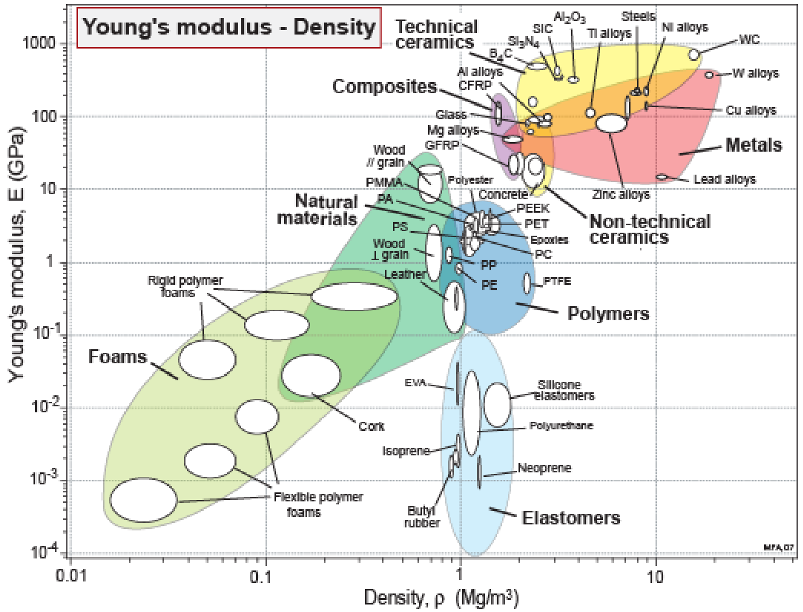
Author	*Title*	*Chapter*
Callister	*"Materials Science and Engineering: an Introduction"*	6
Budinski	*"Engineering Materials: Properties and Selection"*	2
Askeland	*"The Science and Engineering of Materials"*	6
Shackelford	*"Introduction to Materials Science for Engineers"*	6
Ashby et al	*"Materials: Engineering, Science, Processing, Design"*	4, 5

HELP, Video tutorials, …



Creating charts

Charts

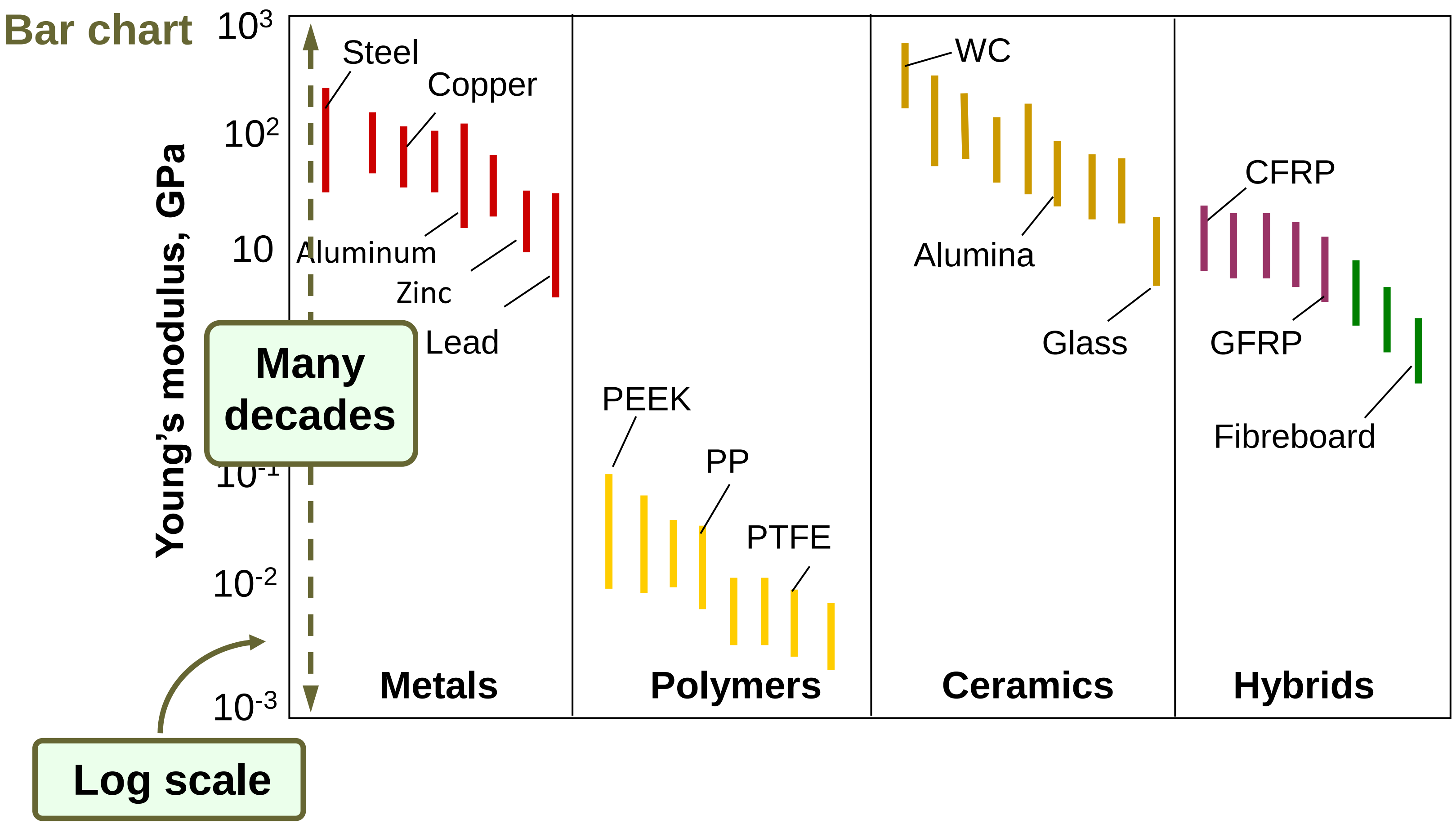


- Exploring relationships: property charts
- Making charts
- Custom subsets, adding your own materials
- Report writing

Bar charts

Data sheets = numbers, words

*We want **meaning*** → **Property charts**



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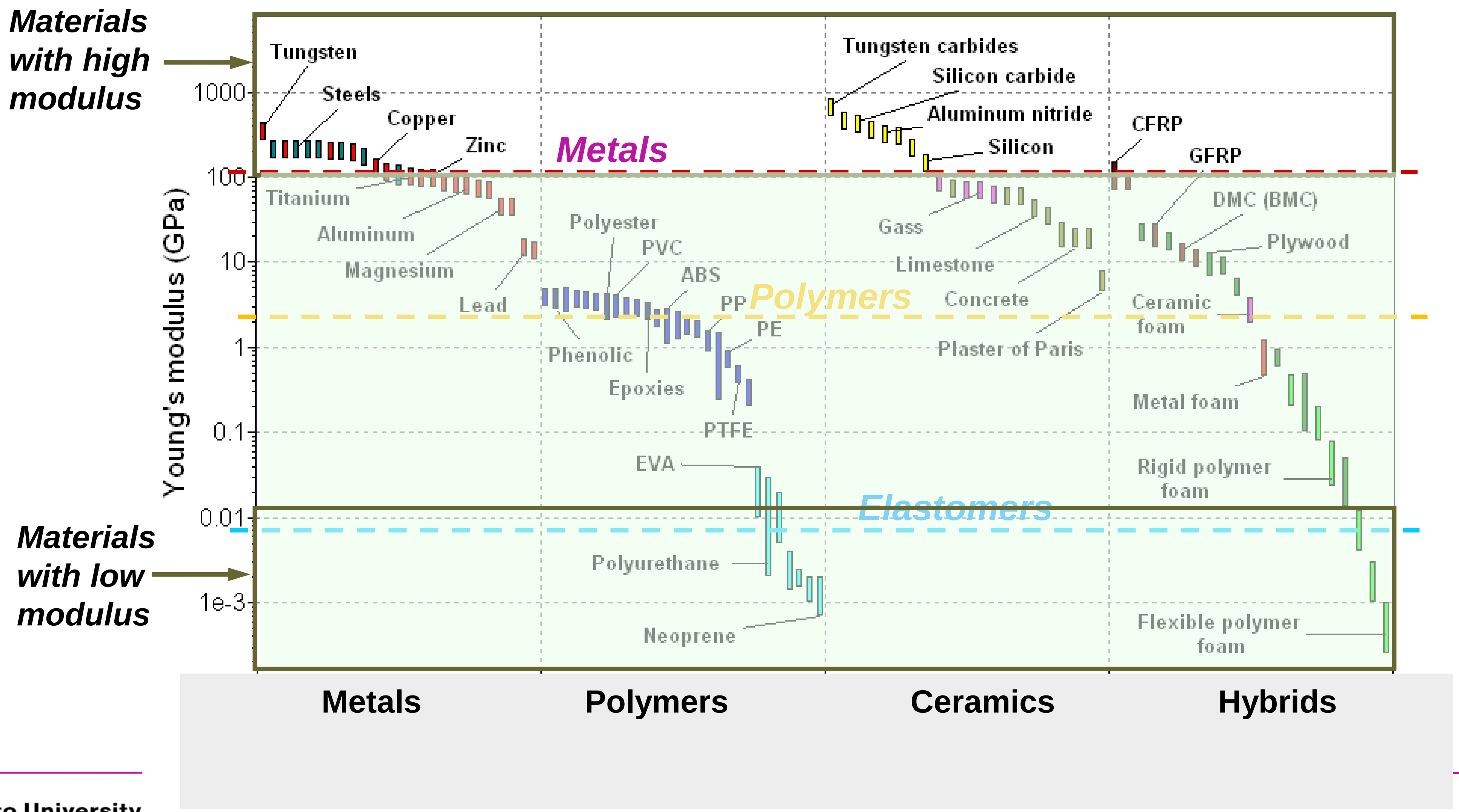
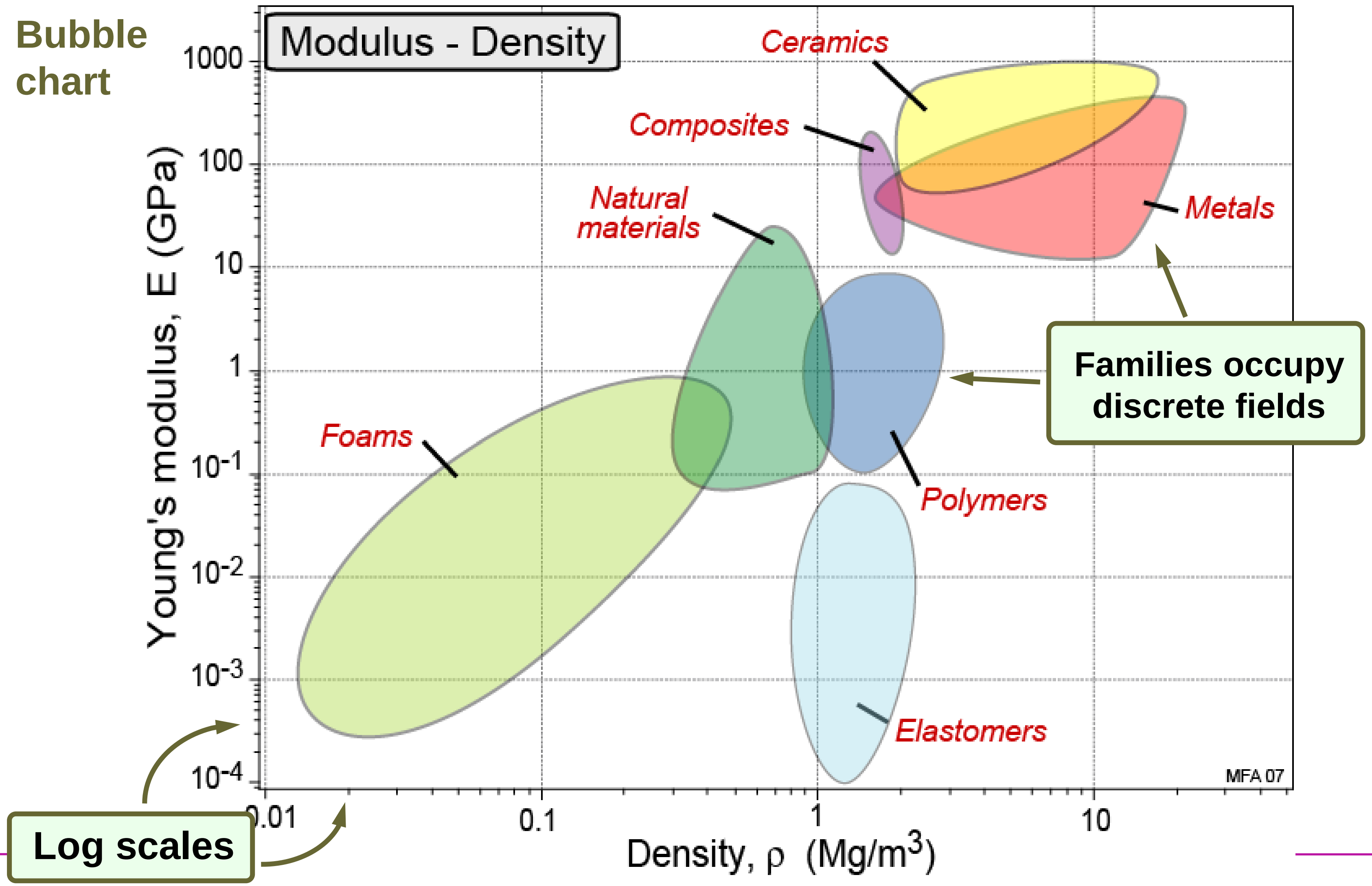
Bar-chart created with *GRANTA EduPack*



Bubble charts

Bubble chart



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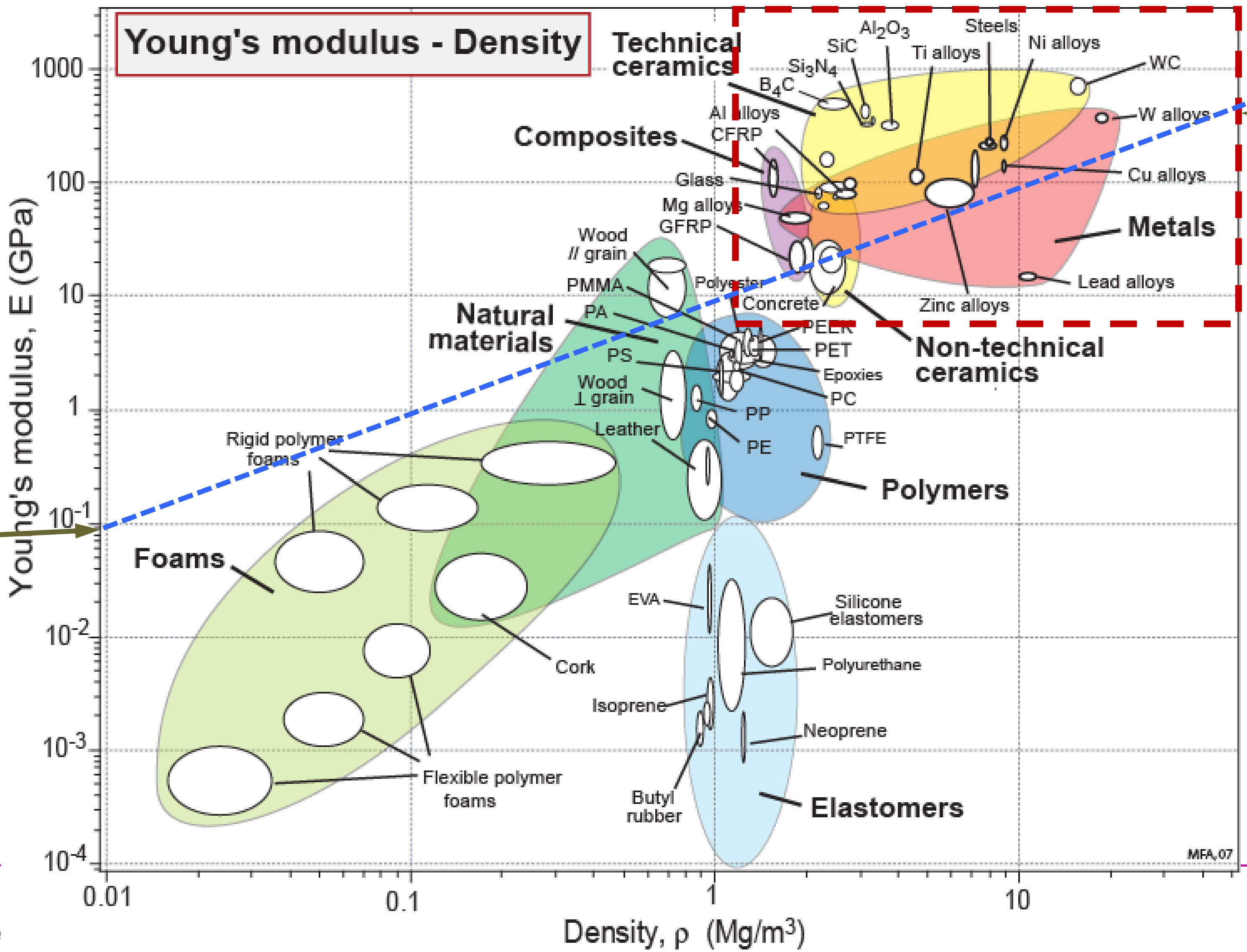
Bubble chart created with CES EduPack



Display line:
Materials with constant specific stiffness [E/ρ]

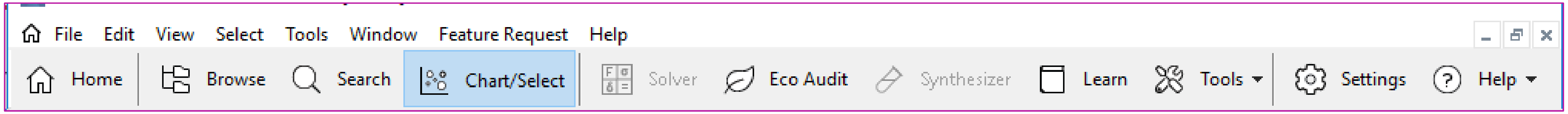
Display Box:
Materials with high Modulus and Density

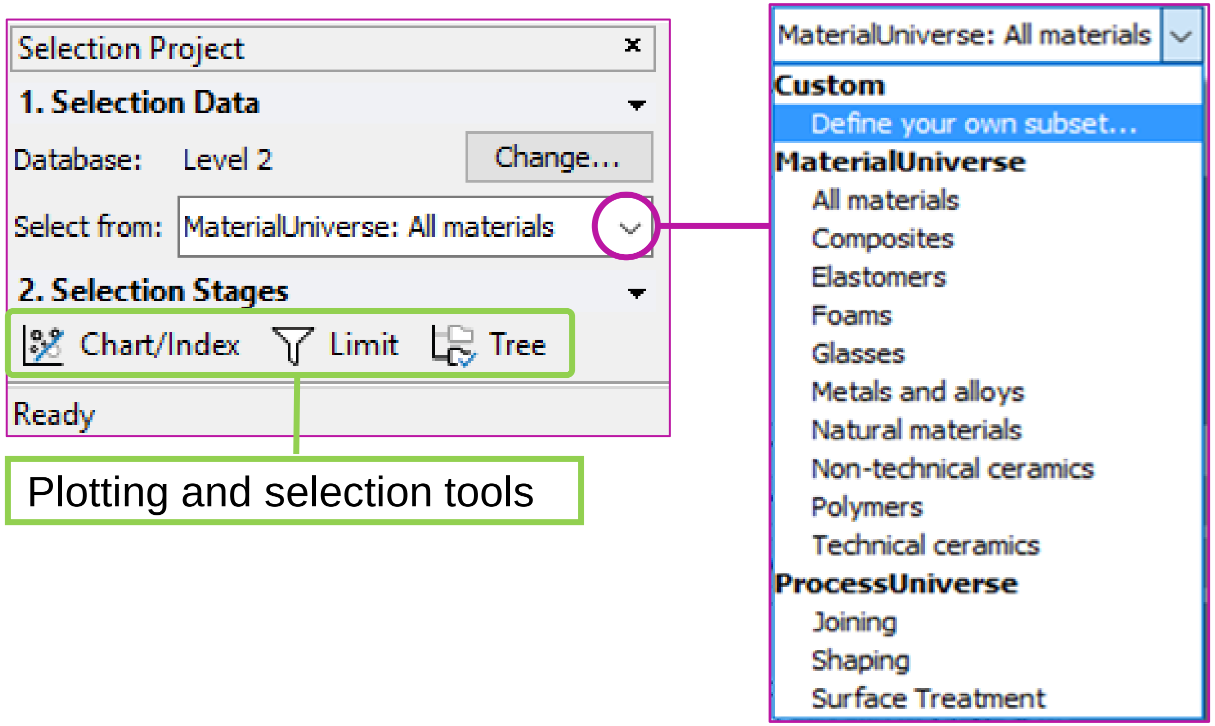
Table chart

Discrete data

Composites	Plastics
Foams	Non-technical ceramics
Metals	Technical ceramics
Elastomers	Natural materials

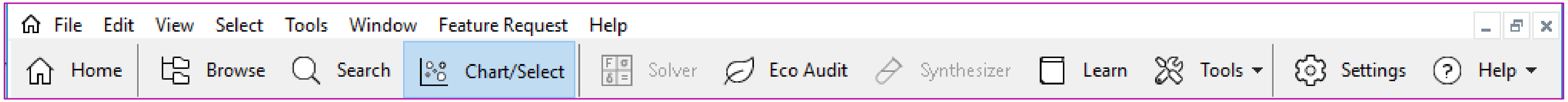
Creating charts for selection

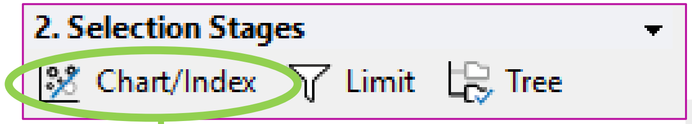




Plotting and selection tools

Creating charts for selection



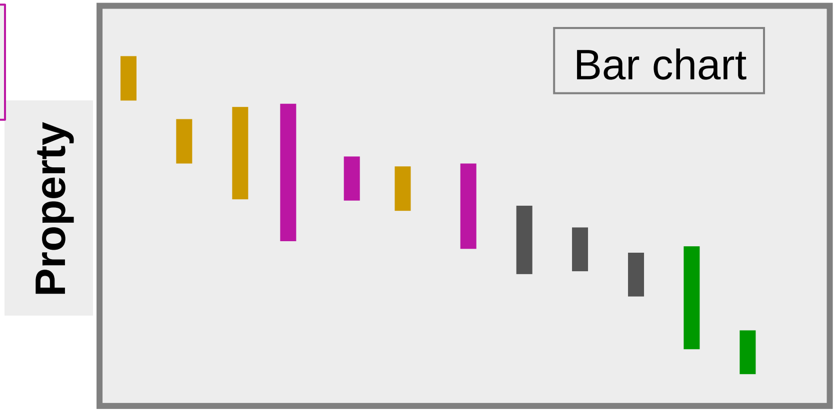


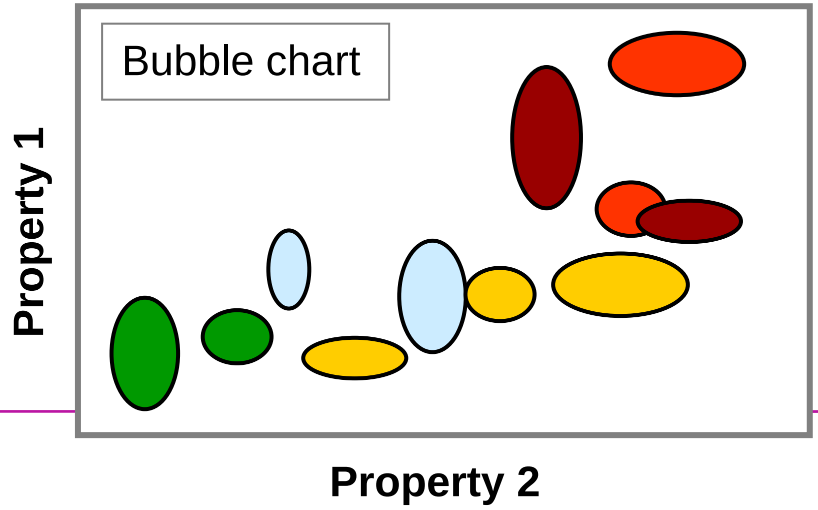
Choose:

X-Axis | Y-Axis

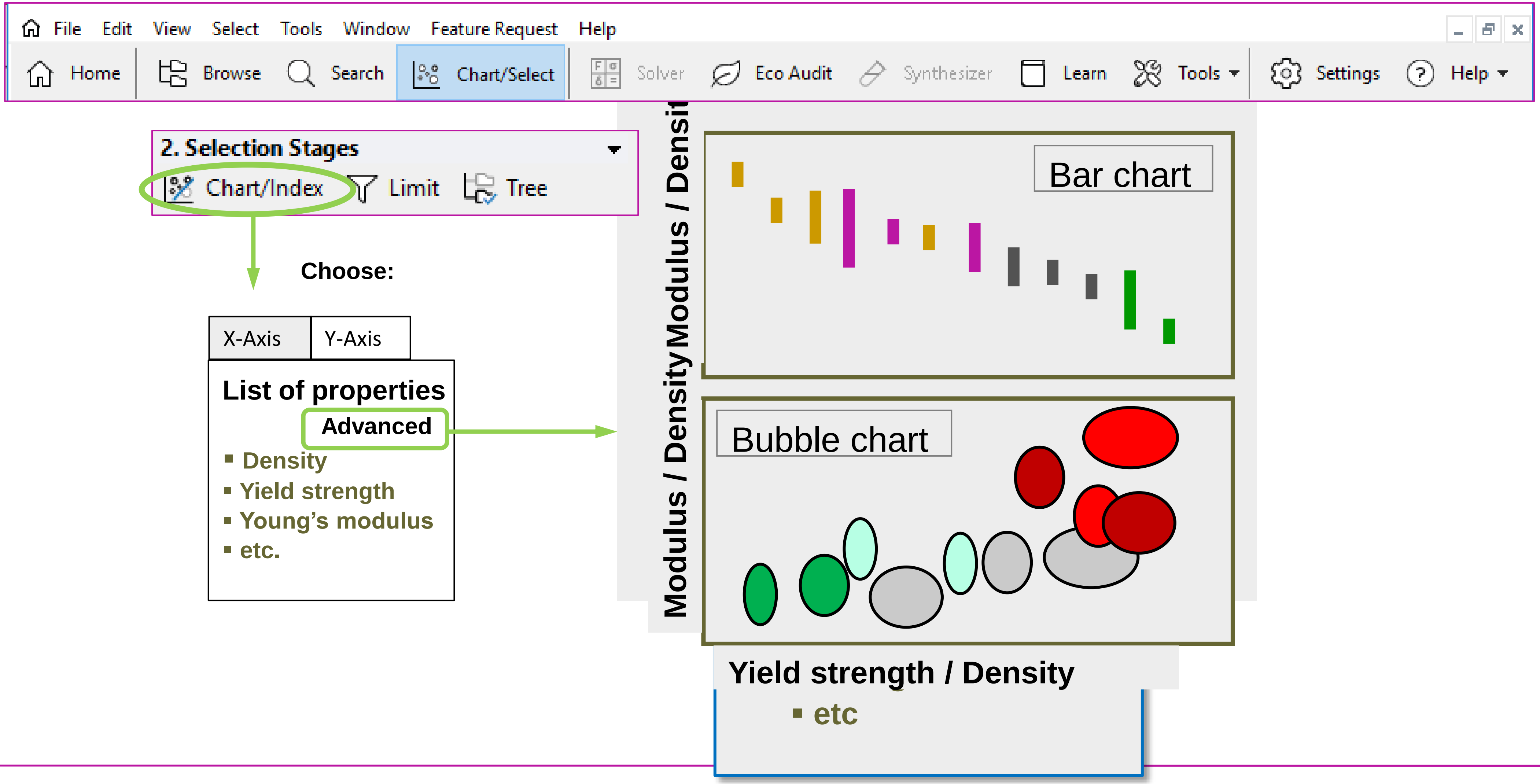
List of properties

- **Density**
- **Yield strength**
- **Young's modulus**
- **etc.**

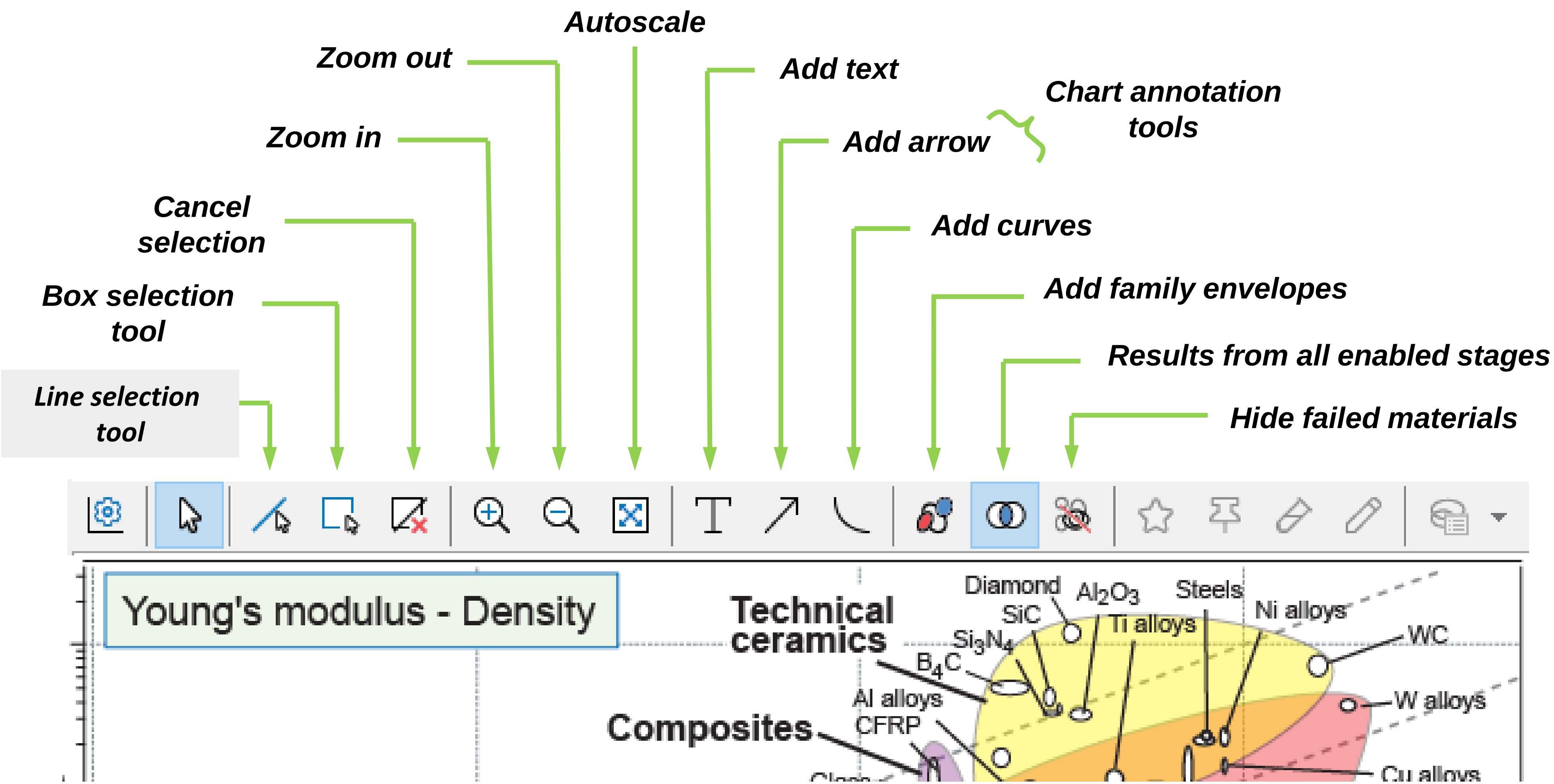




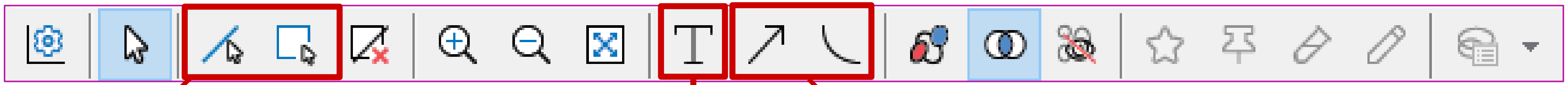
Creating advanced charts for selection



The chart-management tool bar



The line, box and curve tools

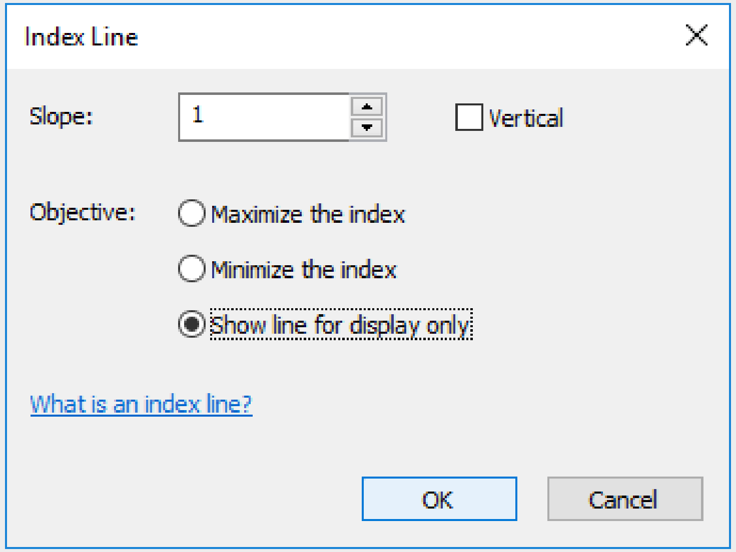


Add **boxes** and **lines**

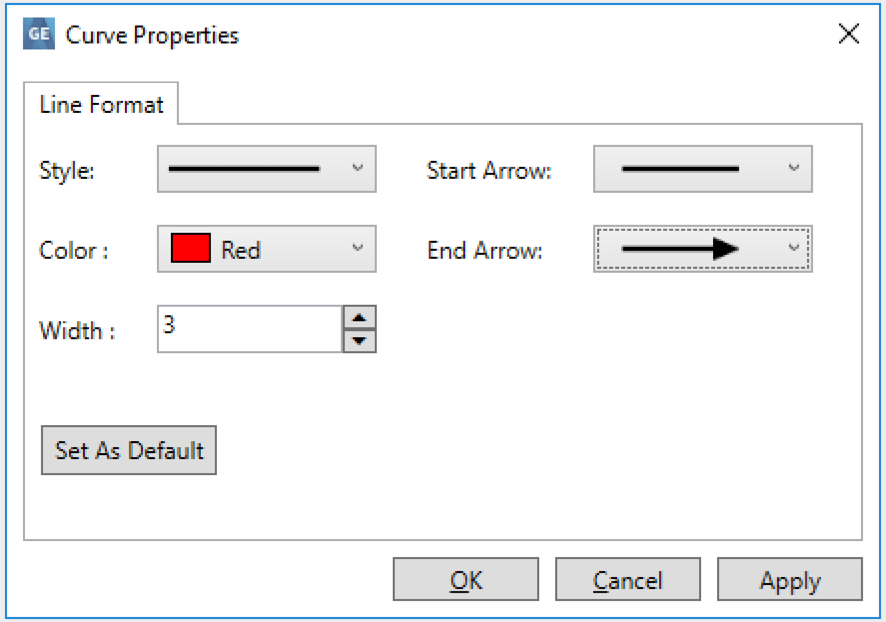
Add **text** to chart

Display **curves** and **arrows**

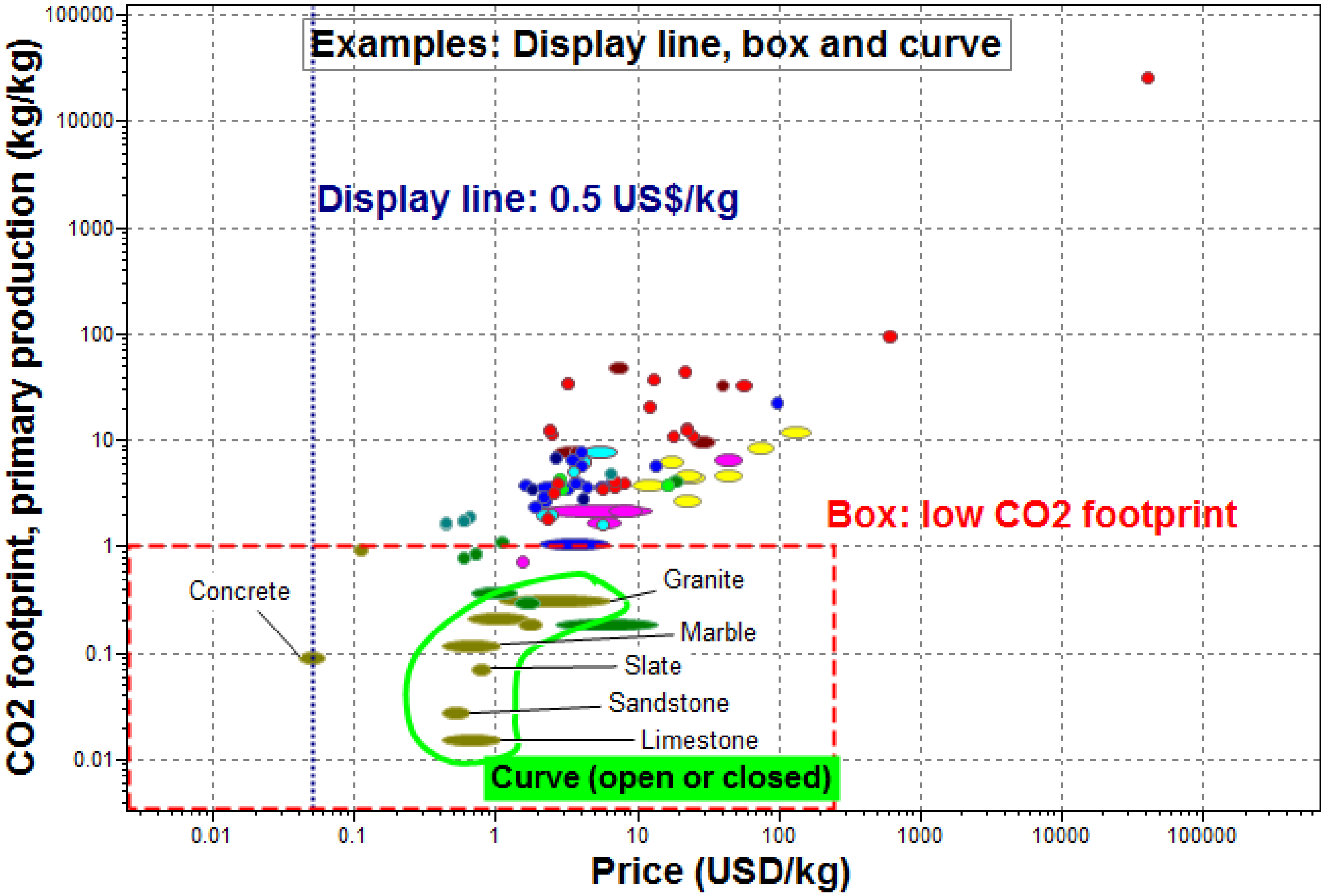
For annotation, select display only:



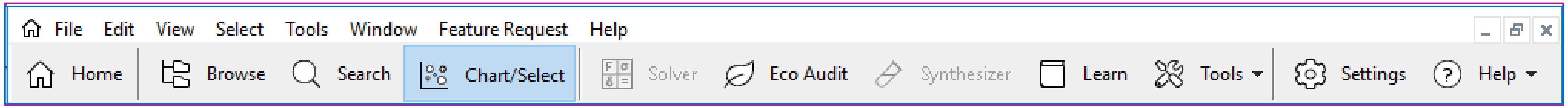
Right-click on line, box or curve to format:

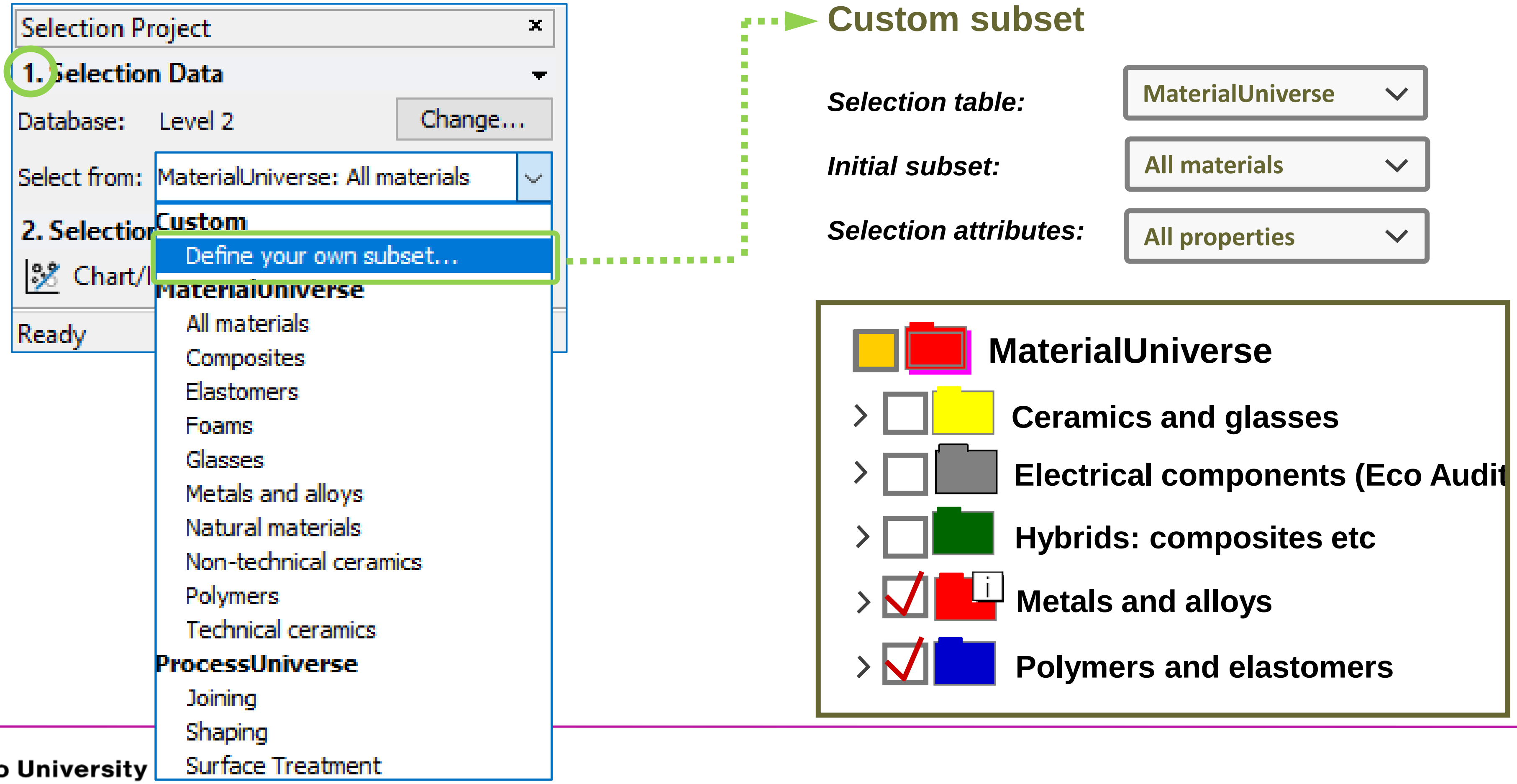


Annotation tools in charts

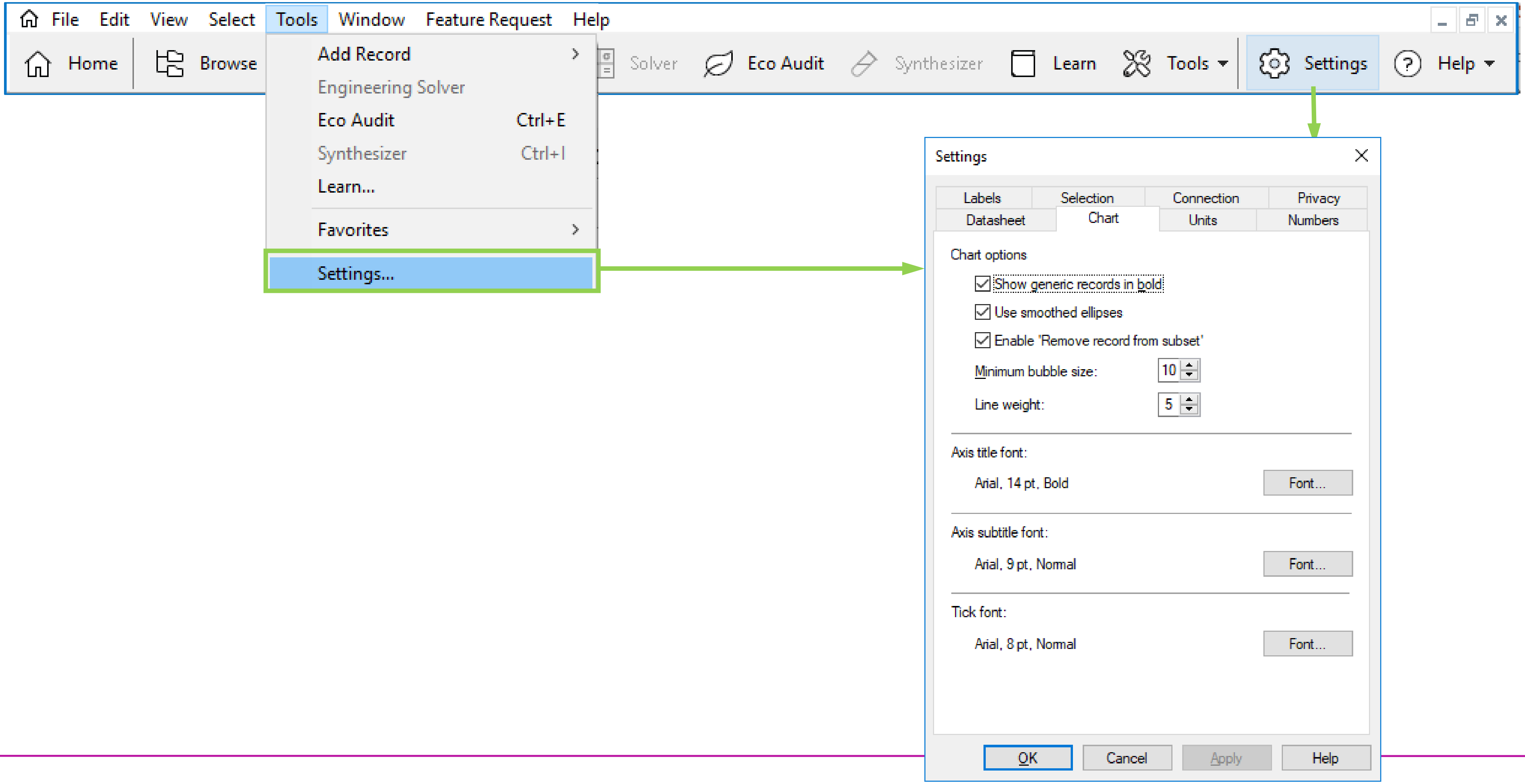


Custom subsets

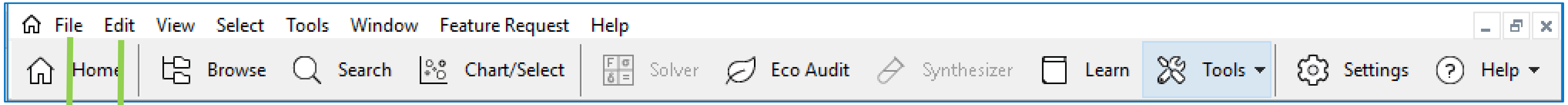




Changing the Chart settings (labels etc.)



Saving projects, report writing



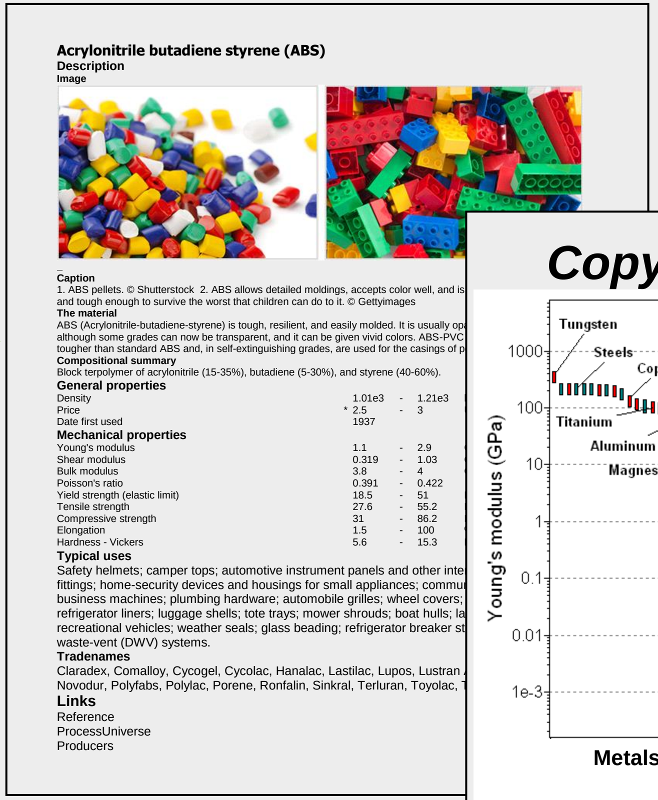
Open project
Save
Print

Cut
Copy
Paste….

Clip-board

To WORD

Paste



Acrylonitrile butadiene styrene (ABS)
Description
Image

Caption
1. ABS pellets. © Shutterstock 2. ABS allows detailed moldings, accepts color well, and is
and tough enough to survive the worst that children can do to it. © Gettyimages

The material
ABS (Acrylonitrile-butadiene-styrene) is tough, resilient, and easily molded. It is usually op
although some grades can now be transparent, and it can be given vivid colors. ABS-PVC
tougher than standard ABS and, in self-extinguishing grades, are used for the casings of p

Compositional summary
Block terpolymer of acrylonitrile (15-35%), butadiene (5-30%), and styrene (40-60%).

General properties

Density		1.01e3	-	1.21e3
Price	*	2.5	-	3
Date first used		1937		

Mechanical properties

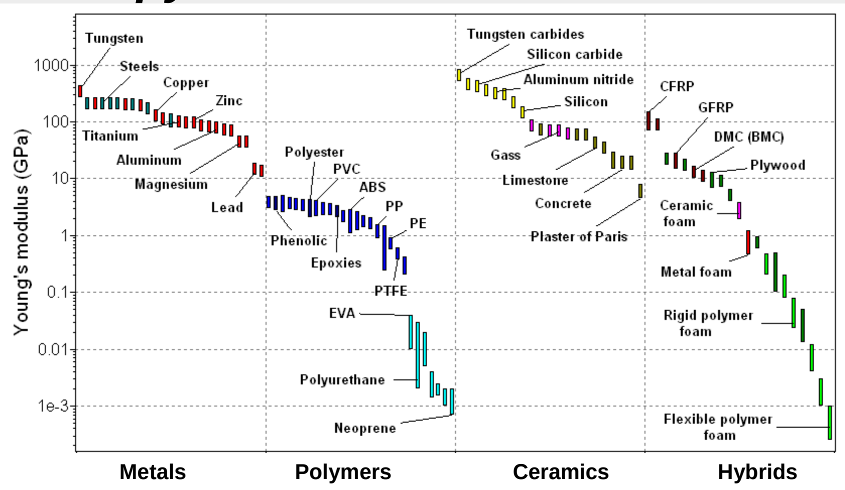
Young's modulus	1.1	-	2.9
Shear modulus	0.319	-	1.03
Bulk modulus	3.8	-	4
Poisson's ratio	0.391	-	0.422
Yield strength (elastic limit)	18.5	-	51
Tensile strength	27.6	-	55.2
Compressive strength	31	-	86.2
Elongation	1.5	-	100
Hardness - Vickers	5.6	-	15.3

Typical uses
Safety helmets; camper tops; automotive instrument panels and other inte
fittings; home-security devices and housings for small appliances; commu
business machines; plumbing hardware; automobile grilles; wheel covers;
refrigerator liners; luggage shells; tote trays; mower shrouds; boat hulls; la
recreational vehicles; weather seals; glass beading; refrigerator breaker st
waste-vent (DWV) systems.

Tradenames
Claradex, Comalloy, Cycogel, Cycolac, Hanalac, Lastilac, Lupos, Lustran
Novodur, Polyfabs, Polylac, Porene, Ronfalin, Sinkral, Terluran, Toyolac,

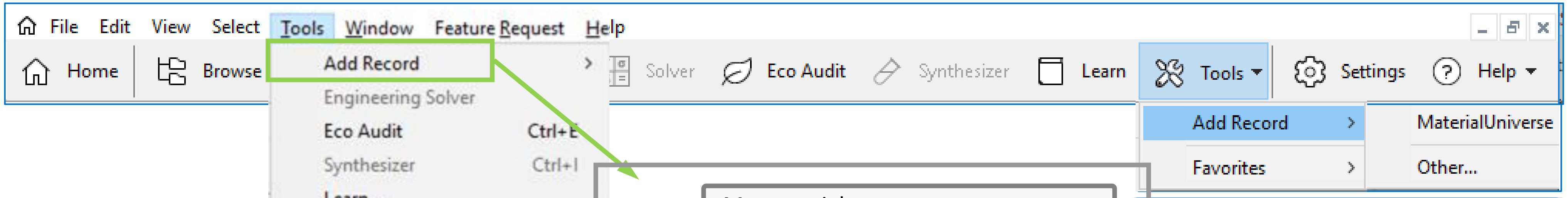
Links
Reference
ProcessUniverse
Producers

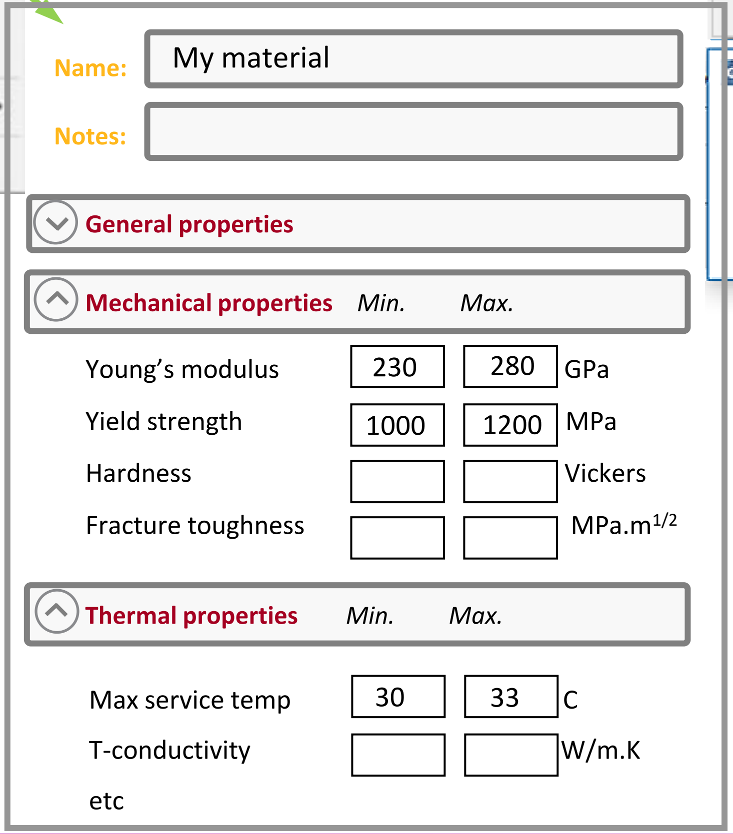
Copy - Paste

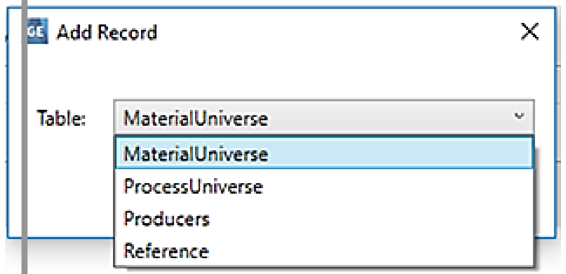


For best results
Paste Special -
Device Independent Bitmap.

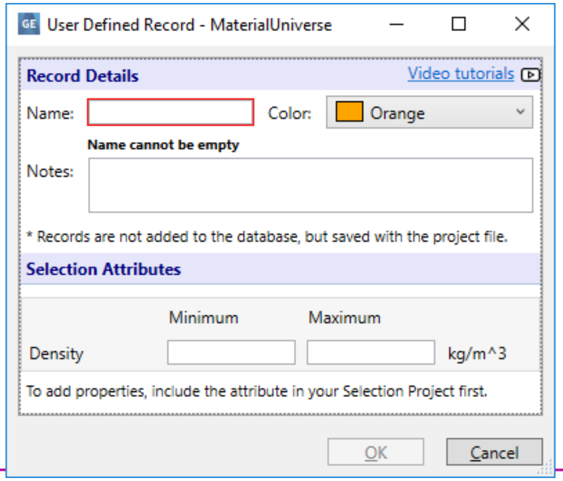
Making your own records





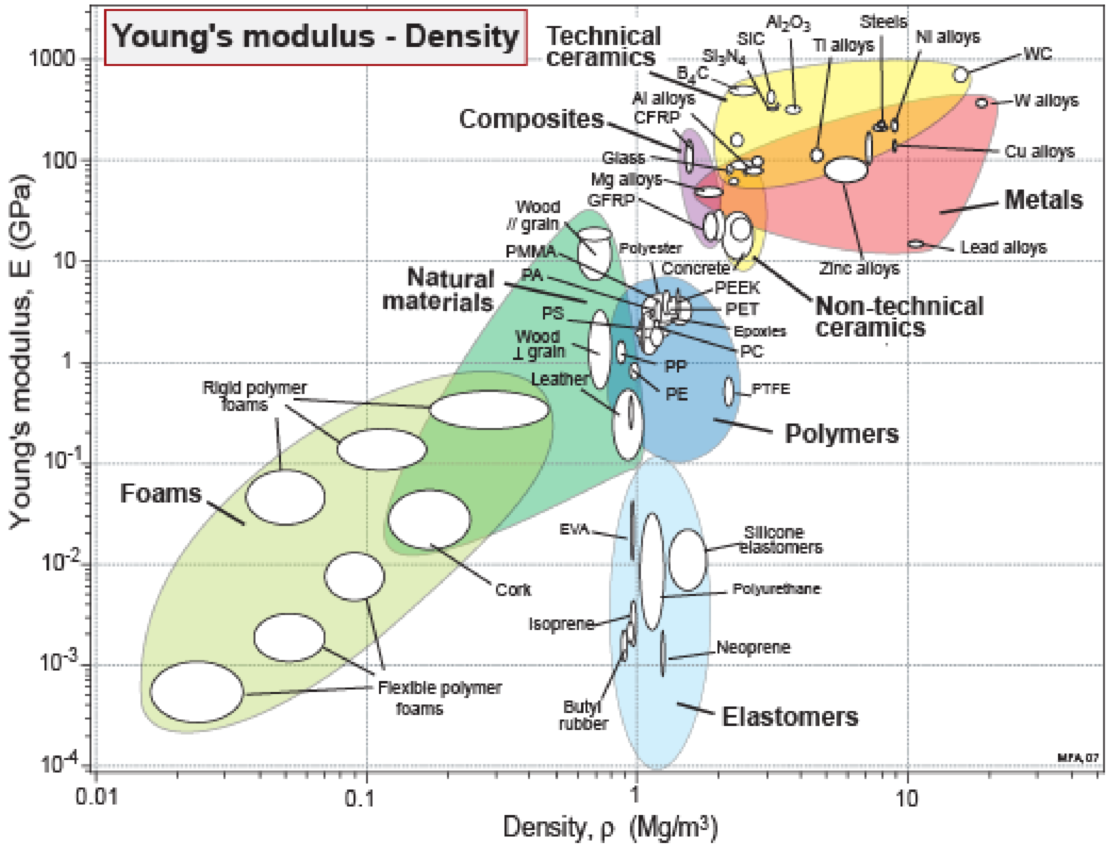


Or, right click on a chart to add limited data to it…



Make selection

Selection procedure



- Translation: deriving material index
- Screening: applying attribute limits
- Ranking: indices on chart
- Documentation

The selection strategy: materials

Design requirements:

expressed as

Constraints *and*

Objectives

Data:

Material attributes

Process attributes

Documentation

Able to be molded
Water and UV resistant
Stiff enough
Strong enough
As cheap as possible
(As light as possible)

Comparison engine

- **Screening**
- **Ranking**
- **Documentation**

Density
Price
Modulus
Strength
Durability
Process compatibility
More…….

Final selection

Translation is important

Translation: *"express design requirements as constraints and objectives"*

Design requirements

Typical Constraints

What essential conditions must it meet ?

- ***Be strong enough***
- ***Conduct electricity***
- ***Tolerate 250˚C***
- ***Be able to be cast***

Typical Objectives

What measure of performance is to be maximized or minimized ?

- ***Mass***
- ***Volume***
- ***Eco-impact***
- ***Cost***

Screening: *"use constraints to eliminate materials that can't do the job"*

What is a “material index”?

Component performance is limited by either:

- a single material property **e.g. tensile strength**, $\boxed{\sigma_{ts}}$
- a material property group, **e.g. modulus / density**, $\boxed{E / \rho}$

The ***material index*** *for the design*

To maximize performance:

- First apply all **constraints**
- Then select materials with the **biggest or smallest index**

Simple one-property indices

Protective visor for motorcyclists

Design requirement

Constraints

- Transparent - of optical quality
- Able to be molded

Objective

- As tough as possible – maximize fracture toughness K_{1c}

The material index: choose material with largest K_{1c}

Alternative objective

- As cheap as possible – minimize material cost C_m

The material index: choose material with smallest C_m

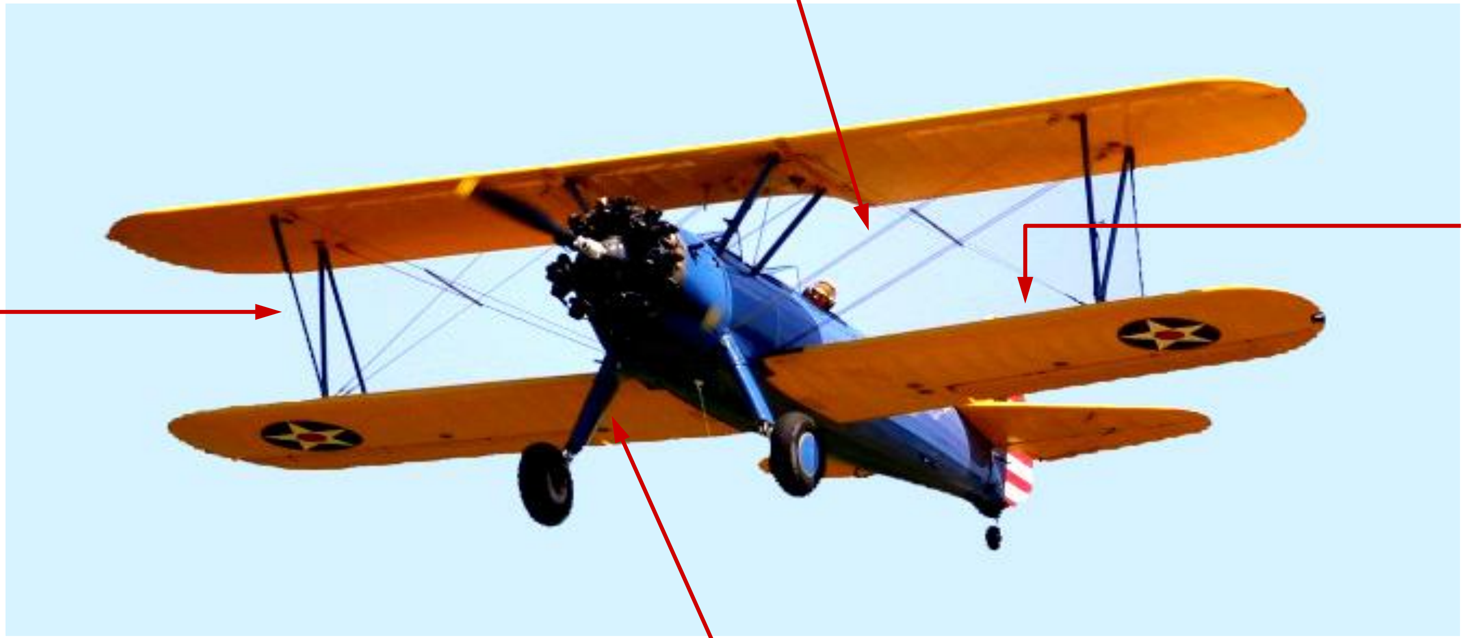
Minimum weight design - indices

Tensile ties

$$\left(\frac{\sigma_y}{\rho}\right)$$

Compression strut

$$\left(\frac{E^{1/2}}{\rho}\right)$$



Main spar - beam

$$\left(\frac{E^{1/2}}{\rho}\right)$$

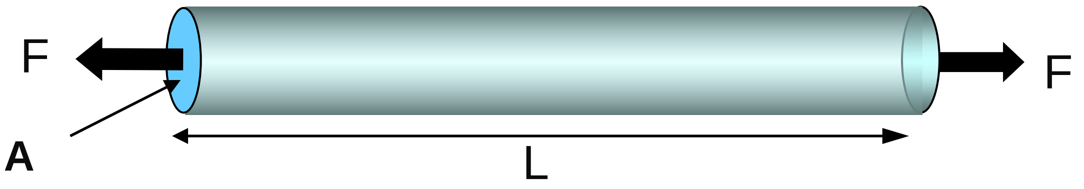
Undercarriage - bending and compression

$$\left(\frac{\sigma_y^{2/3}}{\rho}\right)$$

E = Young's modulus
ρ = Density
σ_y = Yield strength

Index for a strong, light tie-rod

Strong tie of length L and minimum mass



Function

Tie-rod

Constraints

- *Length L is specified*
- *Must not fail under load F*

m = mass
A = area
L = length
ρ = density
σ_y = yield strength

Equation for constraint on A:

$$\boxed{F/A < \sigma_y}$$

Objective

Minimize mass m:

$$\boxed{m = A\,L\,\rho}$$

Performance metric

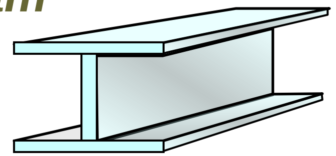
$$\mathbf{m} = \mathbf{F\,L}\left(\frac{\boldsymbol{\rho}}{\boldsymbol{\sigma}_{\mathbf{y}}}\right)$$

Chose materials with largest $M = \left(\frac{\boldsymbol{\sigma}_{\mathbf{y}}}{\boldsymbol{\rho}}\right)$

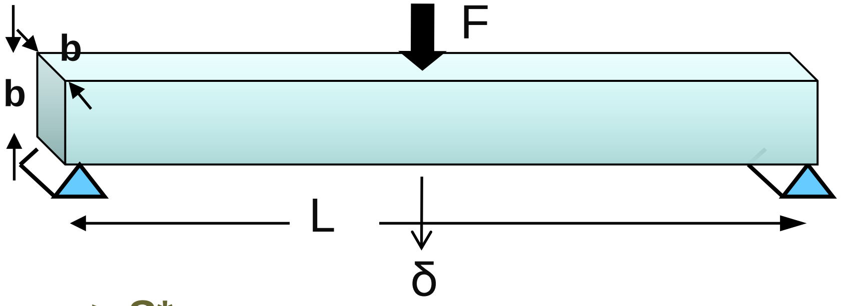
Index for a stiff, light beam

Function

Beam



Stiff beam of length L and minimum mass



Square section, area $A = b^2$

Constraints

- ***Length L is specified***
- ***Must have bending stiffness > S****

Equation for constraint on A:

$$S = \frac{F}{\delta} = \frac{CEI}{L^3} = \frac{CEA^2}{12L^3}$$

m = mass
A = area
L = length
ρ = density
S = stiffness (F/δ)
This beam: $\delta = FL^3/CEI$
C = constant (here, 48)
E = Young's modulus
I = second moment of area
($I = b^4/12 = A^2/12$)

Objective

Minimize mass m:

$$m = A L \rho$$

Performance metric

$$m = \left(\frac{12L^5 S^*}{C}\right)^{1/2} \left(\frac{\rho}{E^{1/2}}\right)$$

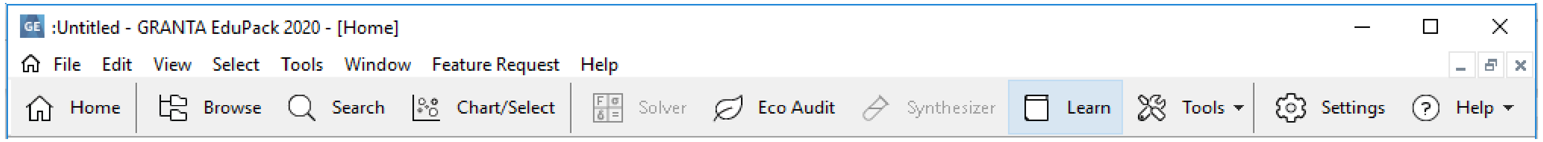
Chose materials with largest $M = \left(\frac{E^{1/2}}{\rho}\right)$

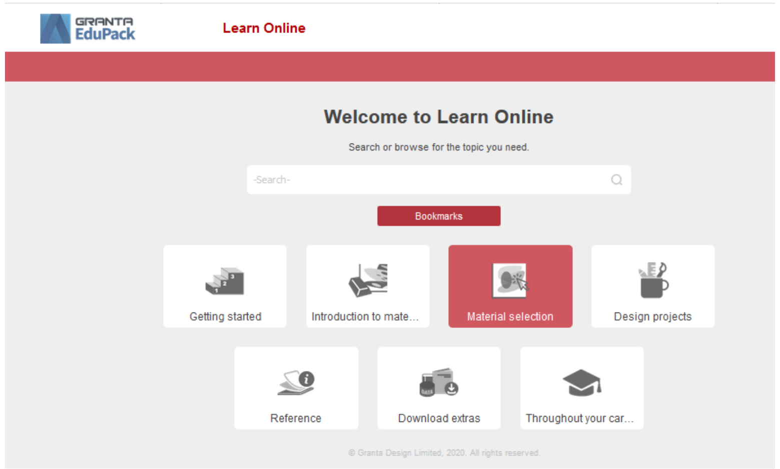
Material index

Component performance is limited by either:

- one single material property **e.g. tensile strength**, $\boldsymbol{\sigma_{ts}}$
- a group of material properties. **modulus / density**, $\mathbf{E / \rho}$

material index
for the design





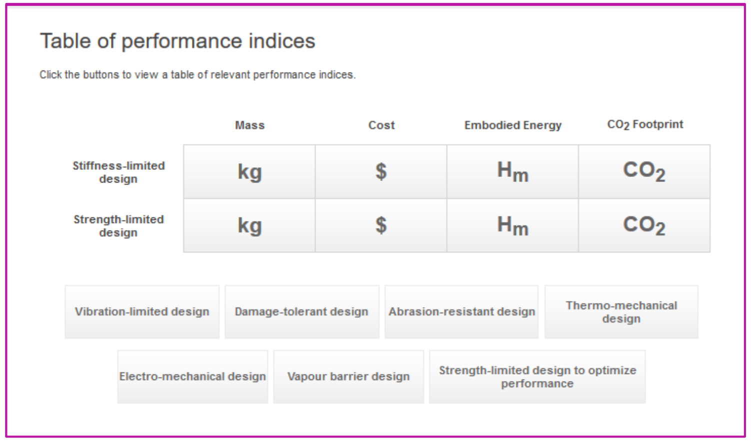


Table of performance indices

Click the buttons to view a table of relevant performance indices.

	Mass	Cost	Embodied Energy	CO_2 Footprint
Stiffness-limited design	kg	$	H_m	CO_2
Strength-limited design	kg	$	H_m	CO_2

Vibration-limited design | Damage-tolerant design | Abrasion-resistant design | Thermo-mechanical design

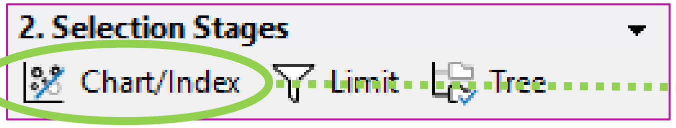
Electro-mechanical design | Vapour barrier design | Strength-limited design to optimize performance

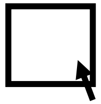
To maximize performance:

- First apply all **constraints**
- Then select materials with the **extreme index**

Aalto University
School of Engineering

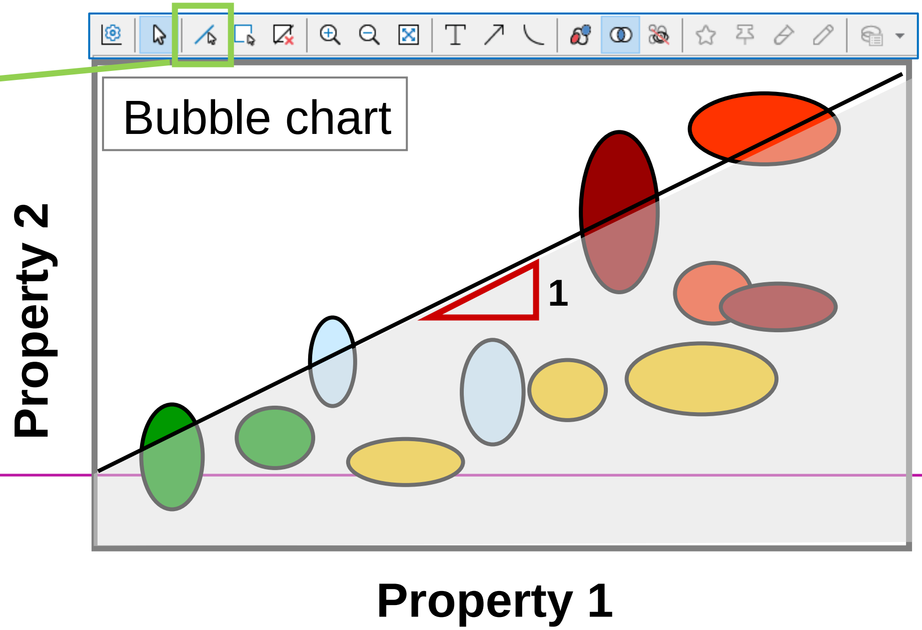
Screening with a CHART STAGE





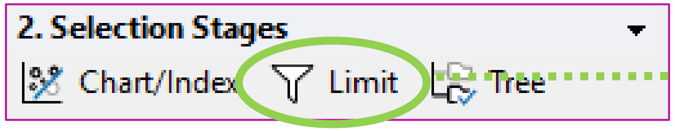
Box selection tool

Line/gradient selection tool

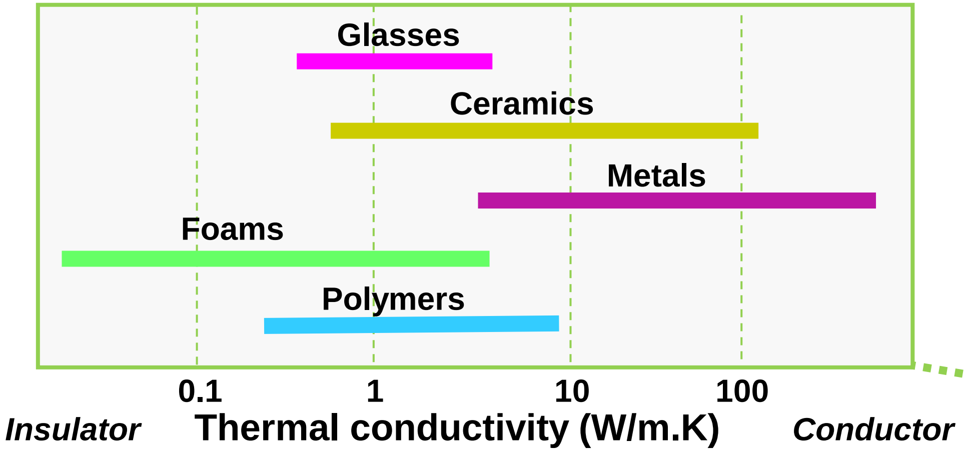


Results *X out of 100 pass*	***Ranking*** *Prop 1*	*Prop 2*
Material 1	2230	113
Material 2	2100	300
Material 3	1950	5.6
etc…		

Screening with a LIMIT STAGE

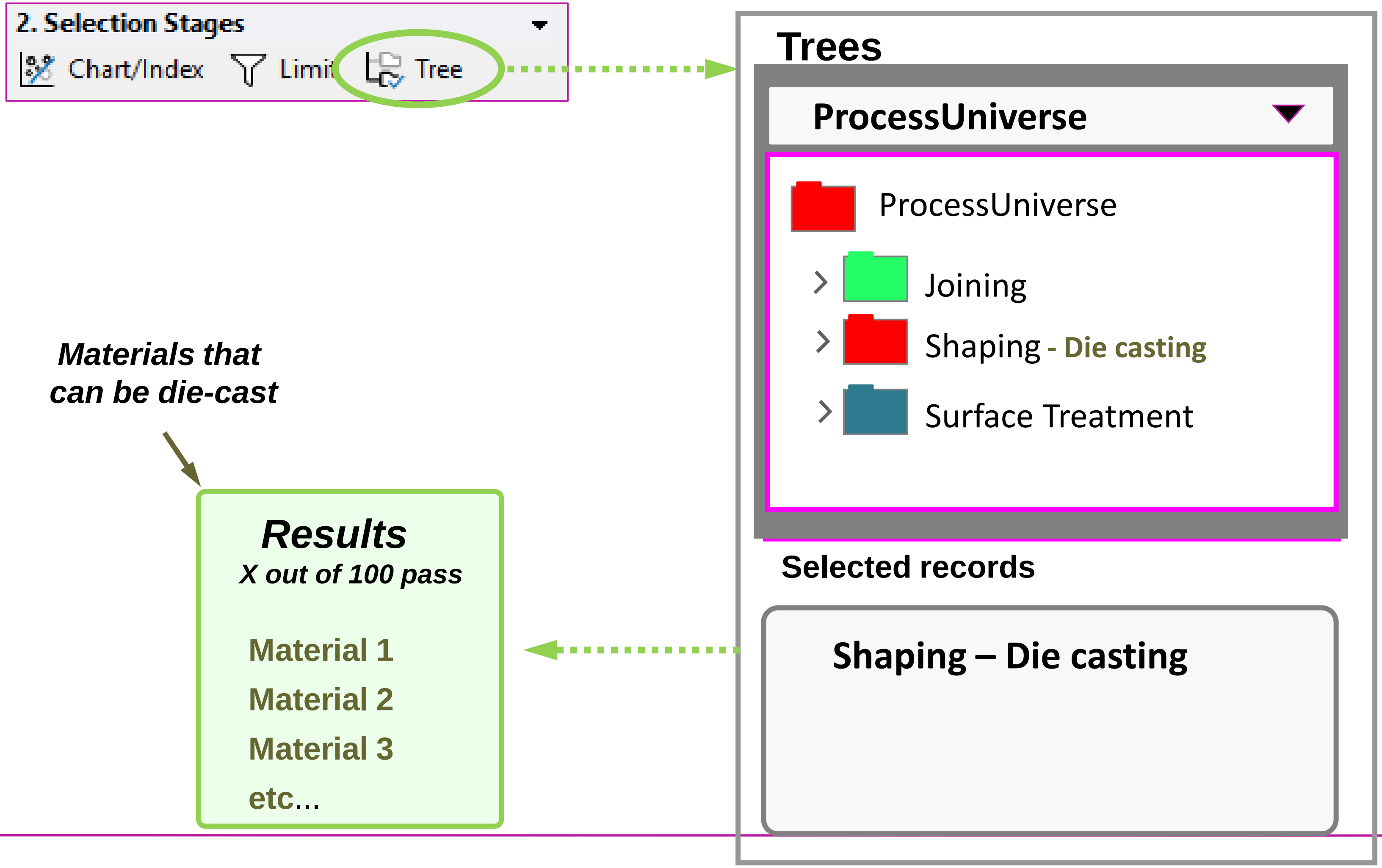


General properties			
Mechanical properties	*Min.*	*Max.*	
Young's modulus	100		GPa
Yield strength	50		MPa
Hardness	70		Vickers
Fracture toughness	16		$MPa.m^{1/2}$
Thermal properties	*Min.*	*Max.*	
Max service temp	200		C
T-conductivity		1	W/m.K
T-expansion		10	10^{-6}/C
Specific heat	1600		J/kg.K
Electrical properties			
Eco properties			

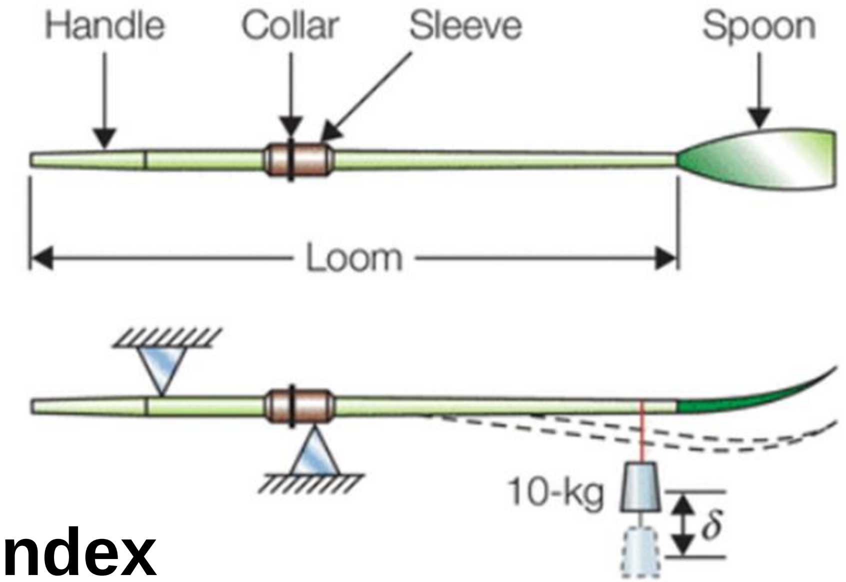


Results *X out of 100 pass*	***Ranking*** *Prop 1*	*Prop 2*
Material 1	2230	113
Material 2	2100	300
Material 3	1950	5.6
etc...		

Screening with a TREE STAGE



Example task: Materials for Oars



Step 1 – Determine Design Requirements

…

Step 2 – Determine Material performance index

… *(explanations with formula, eq.s …)*

Step 3 – Plot the chart in order to determine the best possible choice

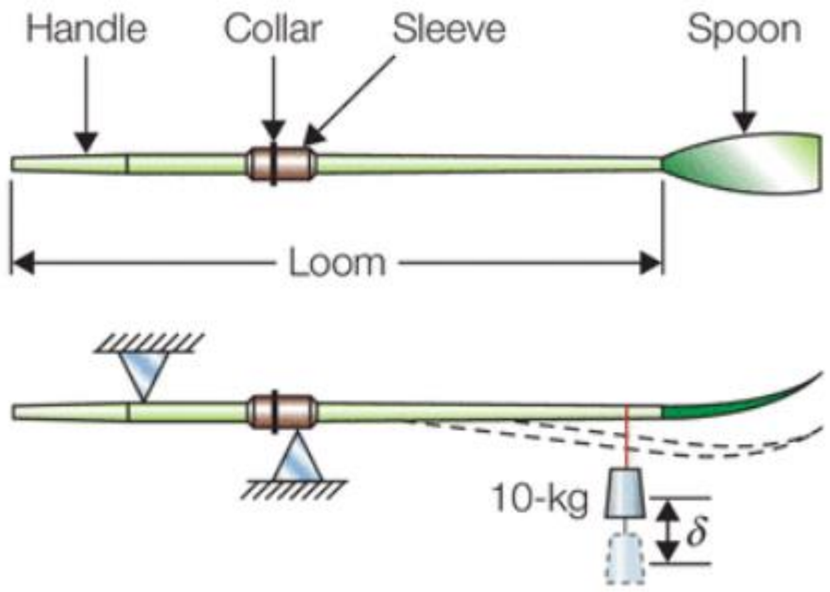
…

Example task: Materials for Oars

<u>Minimize mass</u> for **given bending stiffness** (and length)

$$m = AL\rho \qquad S \propto \frac{EI}{L^3} \propto E\frac{A^2}{L^3}$$

$$m \propto \sqrt{\frac{SL^3}{E}}L\rho = \sqrt{S} \cdot L^{5/2} \cdot \frac{\rho}{\sqrt{E}}$$



Ranking, using charts

Light stiff beam:

Index $\quad \mathbf{M} = \dfrac{\mathbf{E^{1/2}}}{\boldsymbol{\rho}}$

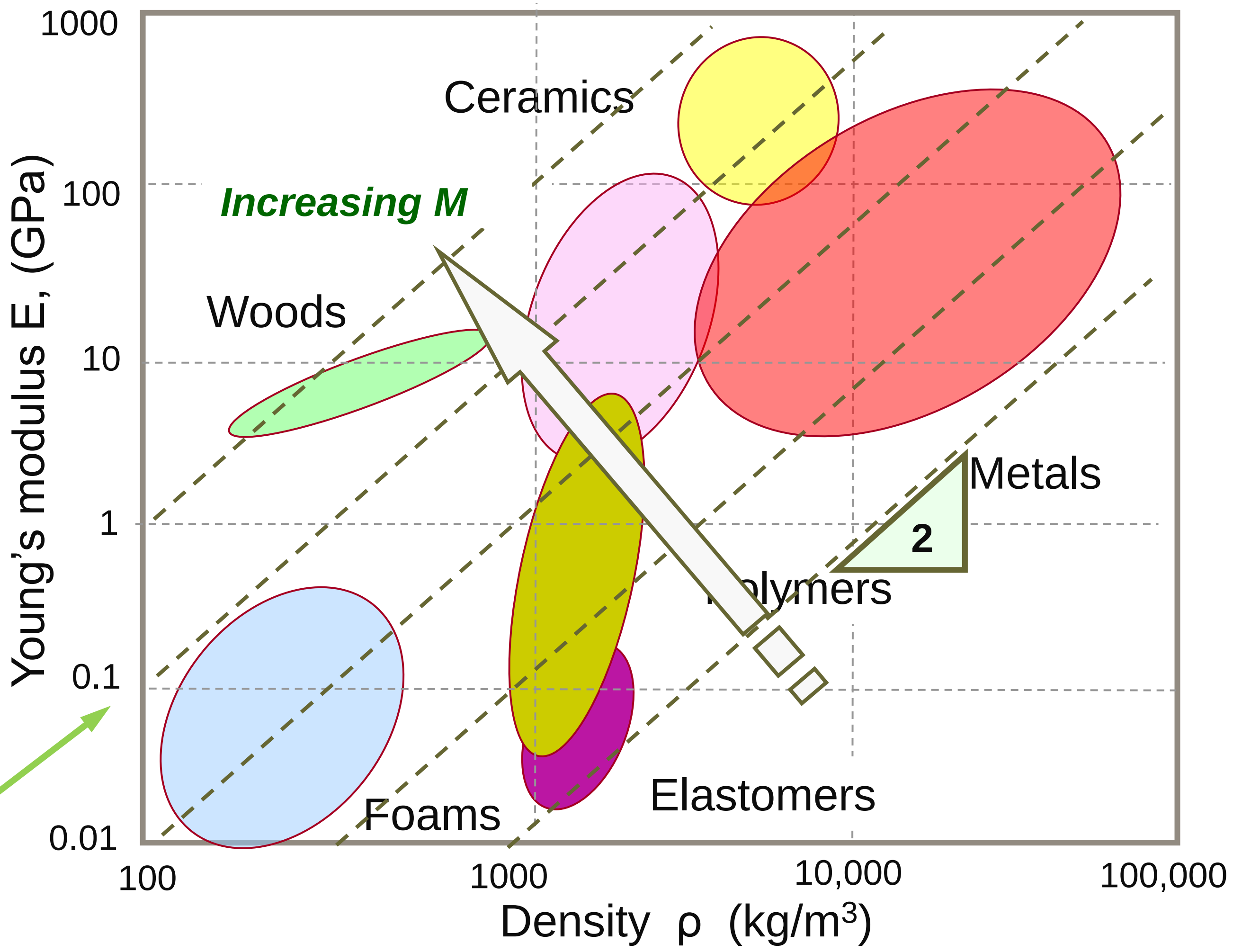
Rearrange:

$$E = \rho^2 M^2$$

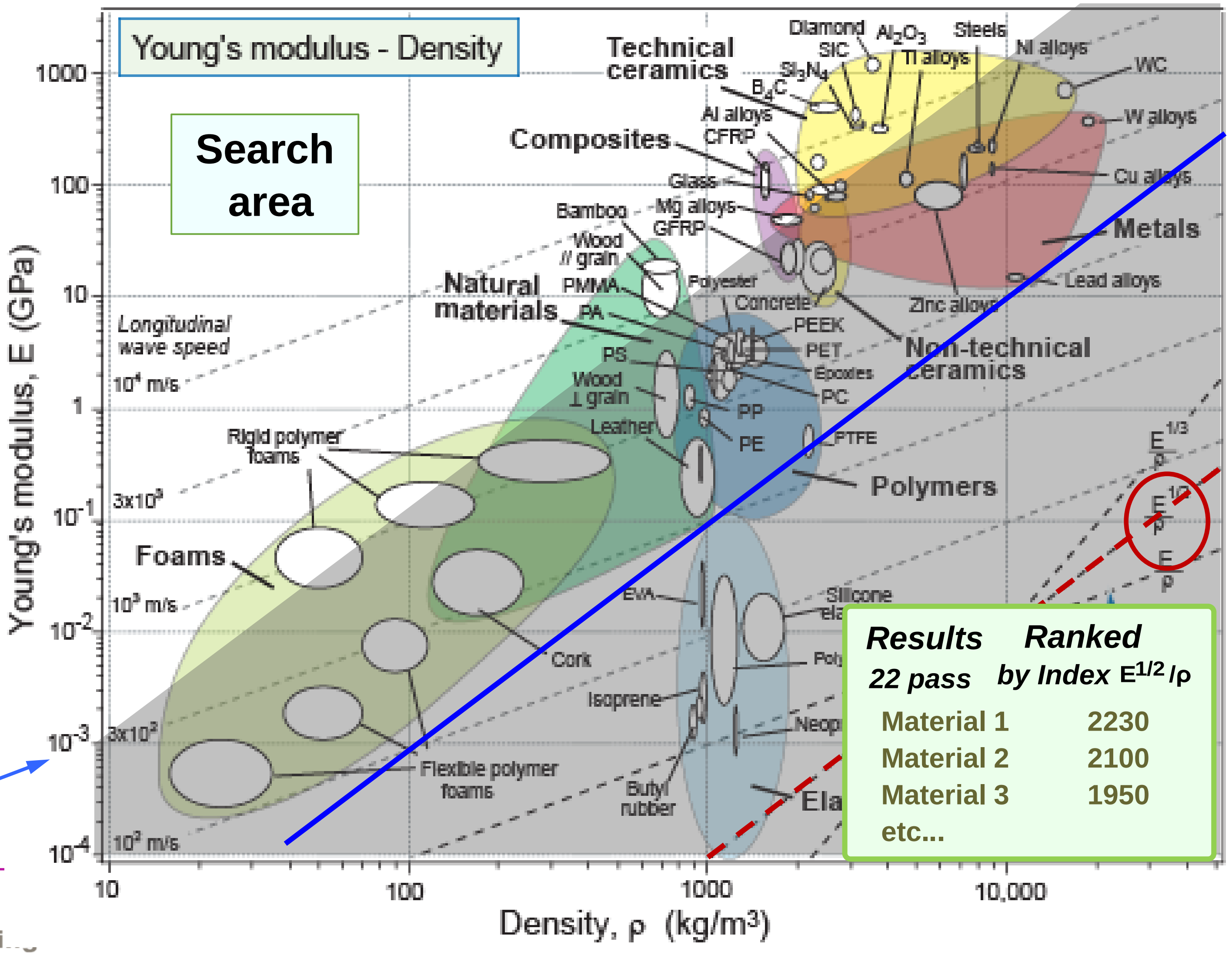
Take logs:

$$\text{Log } E = 2 \log \rho + 2 \log M$$

Function	*Index*	*Slope*
Tie	E/ρ	*1*
Beam	$E^{1/2}/\rho$	*2*
Panel	$E^{1/3}/\rho$	*3*

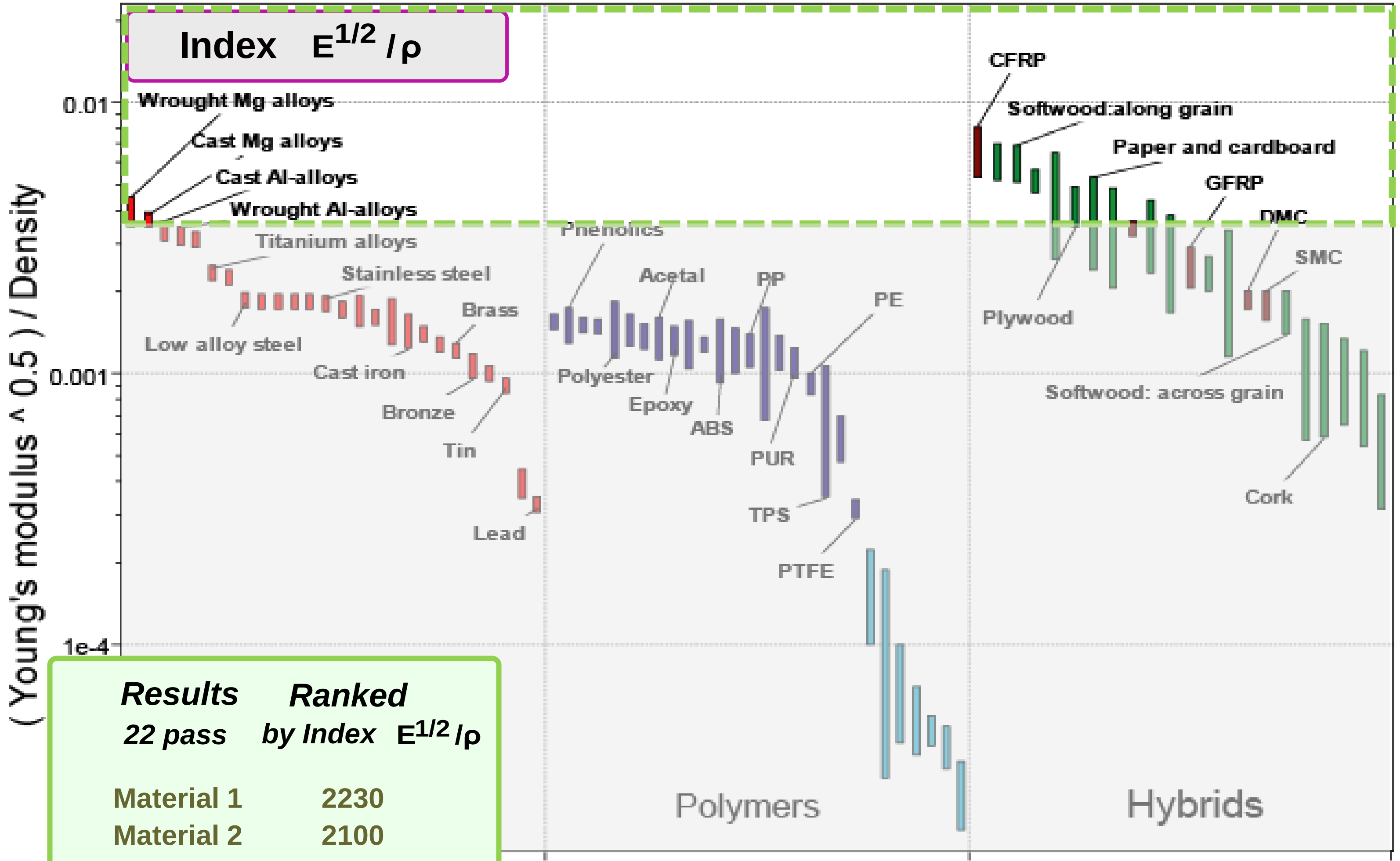


Selection using index in a bubble chart



$$\frac{E^{1/2}}{\rho} = M$$

Selection using index directly on chart axis



Results	***Ranked***
22 pass	***by Index*** $E^{1/2}/\rho$
Material 1	**2230**
Material 2	**2100**
Material 3	**1950**
etc...	

Documentation

Documentation: *“now the number of candidates is small, explore their character in depth”*

Handbooks

Specialized databases

Suppliers’ data sheets

The Internet

Videos for Excercise

Materials Selection with Granta EduPack

Lesson 1: Creating Charts

https://youtu.be/oVH2r8tJrp8?list=PLtt6-ZgUFmMK4aApOUoA85CvaJ_udGDCe

Lesson 2: Formatting Charts

https://www.youtube.com/watch?v=hNA5DBNwm1I&list=PLtt6-ZgUFmMK4aApOUoA85CvaJ_udGDCe&index=2

Summary

- **The selection strategy:**

Translate - Screen - Rank - Documentation

- EduPack allows Screening using **‘Limit – Chart – Tree stages’** in any number and sequence

- The progression:

Data ⇒ **Visualization** (understanding the data) ⇒ **Selection** (using the data)

Questions?

- Contact: MyCourses ‘General discussion’ channel