Project No. lzp-2018/1-0510

Methodology for TRIZ Application in Research Projects

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21.05.2019. TRIZCON2019, Purdue University, West Lafayette, USA

Contents

Motivation

- **Science/research is a large “sector of economy” that produces new knowledge.**
  - There are more than 8 million researchers worldwide (7.5 million in 2013) [1]
  - more than 1.2 million publications annually (1.2 million in 2014) [1].
  - global expenditures in R&D worldwide is about 1 700 billion $ [2].
  - more than 28 000 Universities worldwide [3].
- **The researchers are evaluated by number of quality of their publications**, which solve technological problems, provide new solutions or observations.
- **In science there is no widespread methodology how to achieve good scientific results. High-results are achieved by talented persons**;
- **TRIZ as technology for problem solving can support researchers to achieve excellent scientific results**

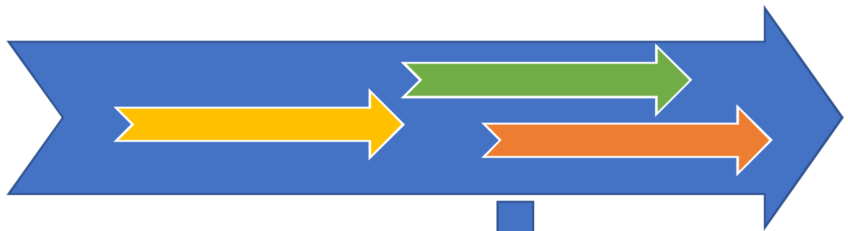
[1] UNESCO science report: towards 2030, https://unesdoc.unesco.org/ark:/48223/pf0000235406

[2] http://uis.unesco.org/apps/visualisations/research-and-development-spending/

[3] http://www.webometrics.info/en/node/54

Description of Scientific work and Research projects

General scheme of scientific work



Flow of the topic development

Selected problem

1. Design of research

2. Experimental path

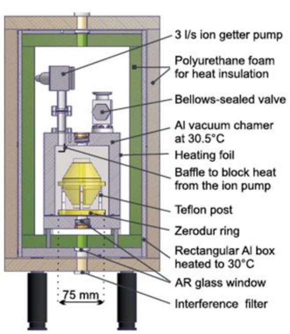
- 2.1. Design of experiments
- 2.2. Construction of test setup
- 2.3. Experiments
- 2.4. Measurement Results

3. Theory path

- 3.1. Selection of the model situation
- 3.2. Construction of mathematical model
  - 3.2.1. Analytical formulas
  - 3.2.2 Computer program
- 3.3. Data simulation
- 3.4. Theoretical Results

4. Comparisson of experimental and theoretical results

5. Data interpretation



$$P = \frac{3}{4\pi^2}\left(\frac{\lambda}{n}\right)^3 \frac{Q}{V}$$

Example of publication

PHYSICAL REVIEW A **77**, 053809 (2008)

Subhertz linewidth diode lasers by stabilization to vibrationally and thermally compensated ultralow-expansion glass Fabry-Pérot cavities

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(Received 29 January 2008; published 12 May 2008)

We achieved a 0.5 Hz optical beat note linewidth with ~0.1 Hz/s frequency drift at 972 nm between two external cavity diode lasers independently stabilized to two vertically mounted Fabry-Pérot (FP) reference cavities with a finesse of 400 000. Vertical FP reference cavities are suspended in midplane such that the influence of vertical vibrations to the mirror separation is significantly suppressed. This makes the setup virtually immune for vertical vibrations that are more difficult to isolate than horizontal vibrations. To compensate for thermal drifts the FP spacers are made from ultralow-expansion (ULE) glass which possesses a zero linear expansion coefficient. A design using Peltier elements in vacuum allows operation at an optimal temperature where the quadratic temperature expansion of ULE could be eliminated as well. The measured linear drift of such ULE FP cavity of 63 mHz/s was due to material aging and the residual frequency fluctuations were less than ±20 Hz during 16 h of measurement. Some part of the temperature-caused drift is attributed to the thermal expansion of the mirror coatings. Thermally induced fluctuations that cause vibrations of the mirror surfaces limit the stability of our cavity. By comparing two similar laser systems we obtain an Allan instability of 2×10^{-15} between 0.1 and 10 s averaging time, which is close to the theoretical thermal noise limit.

DOI: 10.1103/PhysRevA.77.053809 PACS number(s): 42.55.Px, 42.62.Fi, 06.30.Ft

I. INTRODUCTION

Optical atomic clocks and high-resolution laser spectroscopy require spectrally narrow laser light. Even though external cavity diode lasers in general have broad emission was reported [6] and in 2007 a diode laser at 698 nm with 0.4 Hz linewidth was successfully demonstrated [7]. A dye laser possessing sub-Hz linewidth was already demonstrated in 1999 but with a large and complex vibration isolation setup that consisted of an optical bench suspended on rubber

Optical microcavities

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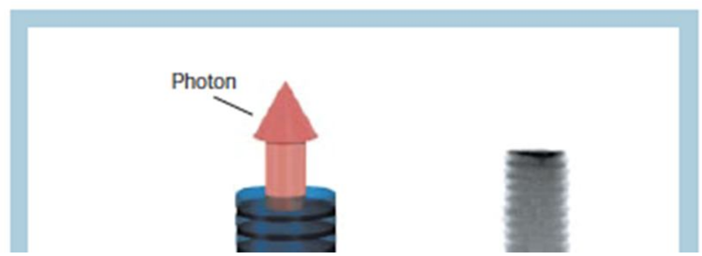
Optical microcavities confine light to small volumes by resonant recirculation. Devices based on optical microcavities are already indispensable for a wide range of applications and studies. For example, microcavities made of active III–V semiconductor materials control laser emission spectra to enable long-distance transmission of data over optical fibres; they also ensure narrow spot-size laser read/write beams in CD and DVD players. In quantum optical devices, microcavities can coax atoms or quantum dots to emit spontaneous photons in a desired direction or can provide an environment where dissipative mechanisms such as spontaneous emission are overcome so that quantum entanglement of radiation and matter is possible. Applications of these remarkable devices are as diverse as their geometrical and resonant properties.

Like its acoustic analogue the tuning fork, the optical microcavity (or microresonator) has a size-dependent resonant frequency spectrum. Microscale volume ensures that resonant frequencies are more sparsely distributed throughout this spectrum than they are in a corresponding 'macroscale' resonator. An ideal cavity would confine light indefinitely (that is, without loss) and would have resonant



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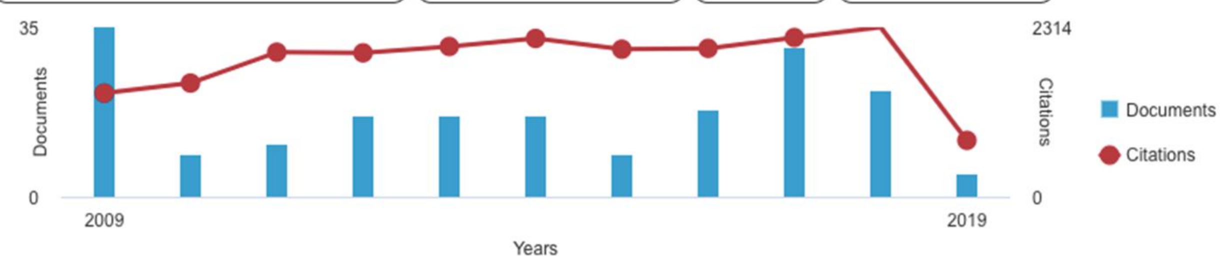
Subject area: Physics and Astronomy | Engineering | Materials Science | Computer Science | Multidisciplinary | Chemistry | Biochemistry, Genetics and Molecular Biology | Earth and Planetary Sciences | Mathematics | Environmental Science

Document and citation trends:



h-index: 74   View *h*-graph

Documents by author
541   Analyze author output

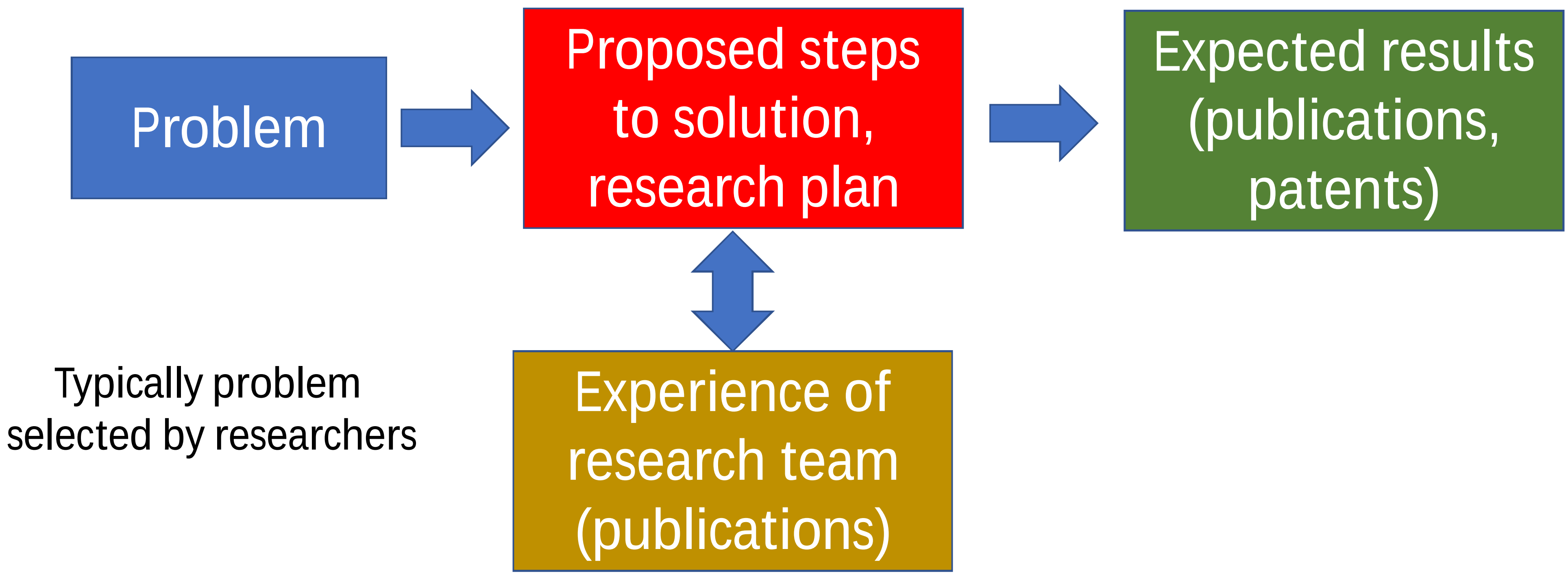
Total citations
26990 by 15655 documents
View citation overview

Scientific Projects

- Public funding is given to research institutes and universities in competition based calls
- Projects: 3 years, 3-7 persons, 600 000 $, outcomes: publications, patents, know-how. Application document 20 - 50 pages.
- Funders:
  - National Science Funds
  - European Framework program – Horizon 2020 Program
  - European Structural Funds
  - University grants
- In USA:
  - National Science Foundation (NSF)
  - Army grants (DARPA)
  - Other
- Industry grants

(typically thorugh direct contact between company and research unit/university)

Grant Proposal general scheme



Advanced general scheme of scientific project calls, proposals

1. Rules of Funder

1.1. Objective of the call
- Research fundamental /applied
- Product development
- Collaboration/networking

1.2. Applicant
Single/several organisations
- research institution/University
- SME

1.3. Research topics

1.4. Expected results
- Publications
- Patents
- New technologies
- Prototypes
- Know-how
- seminars

1.5. Duration

1.6. Budget

1.7. Submission deadline

1.8. Submission template

1.9. Call rules
- Evaluation criteria

2. Project proposal

2.1. Research topic

2.2. Research team
- Leader
- Main researchers
- Assistants, students

2.3. Planned results

2.4. Planned impact

2.5. Planned activities

2.6. Proof for the project's fit to Funder rules and Funding priorities

2.7. Budget

3. Evaluation of project proposal

3.1. Administrative criteria

3.2. Excellence

3.3. Impact

3.4. Implementation

Example of call rules (Horizon 2020)

EN

Horizon 2020

Work Programme 2018-2020

15. Spreading Excellence and Widening Participation

WIDESPREAD-04-2019: ERA Chairs

Specific Challenge: With adequate institutional support outstanding researchers can have a decisive and positive impact on the culture and performance of research institutions. Yet issues such as the availability of research funding, institutional rigidities and access to resources can hamper their mobility to promising institutions, particularly in low R&I performing countries. ERA Chairs actions will address the specific challenge of creating the appropriate conditions for high quality researchers and research managers to move and engage with institutions willing to achieve excellence in the scientific domain of choice and modify their research and innovation landscape.

Scope: The ERA Chairs actions will support universities or research organisations with the objective of attracting and maintaining high quality human resources under the direction of an outstanding researcher and research manager (the "ERA Chair holder") and in parallel implement structural changes to achieve excellence on a sustainable basis.

The Commission considers that proposals requesting a contribution from the EU of EUR 2.5 million, would allow this specific challenge to be addressed appropriately. Nonetheless, this does not preclude submission and selection of proposals requesting lower amounts.

Expected Impact:

- Institutional changes within the ERA Chair host institution allowing for its full participation in the European Research Area.

Example of project proposal

"Project Proposal"
Part C "Project Description"
Project title: **Optical whispering gallery mode microresonator sensors**

1. Scientific Excellence

1.1 Scope of the project

The proposed project is targeted to develop, test and compare several sensors based on Whispering Gallery Mode (WGM) microresonators – temperature sensor, humidity sensor and laser wavelength sensor. Although general principles of these sensors are already described in scientific publications, the practical realization of these sensors is still a challenge. WGM resonators can be made of various forms (ball, toroid, bubble, and other), of various materials (fused silica, MgF_2, CaF_2, polystyrene and other), can be in various state of aggregation (solid, gel, liquid), may have various Q-factors (typically from 10^3 to 10^8)[1] and various coupling schemes can be used (prism, optical fiber, direct irradiation and fluorescence observation, and other). The task is to select the best combination of these parameters to obtain the best (or optimal) performance of WGM resonator with specific sensor capabilities. During a project various experimental schemes will be tested to reveal their advantages and disadvantages. For example, temperature sensing capability of WGM resonator will be tested by measuring a single radiation field, an ordinary and extraordinary component of this field and dual radiation fields. Additionally a single resonator scheme and an array of resonators schemes will be tested, solid and liquid resonators will be tested, absorption and fluorescence fields will be measured. As a result of the project various sensor capabilities of WGM resonators will be revealed and characterized. This will be used later to apply for new projects where specific sensor capabilities of WGM resonators will be analyzed in depth. The other possible after-project scenario is to use obtained results of the project to launch collaboration with SMEs (or to assist start-ups) in practical realization of resonator sensor systems. The project will contribute to [Latvia] Research Priority Areas 2018-2021 on the development of high added value products and on employing the development of new materials and photonics.

Main results of the project will be 2 scientific publications, 2 conference proceeding publications, 1 Latvian patent application.

1.2. State of the art

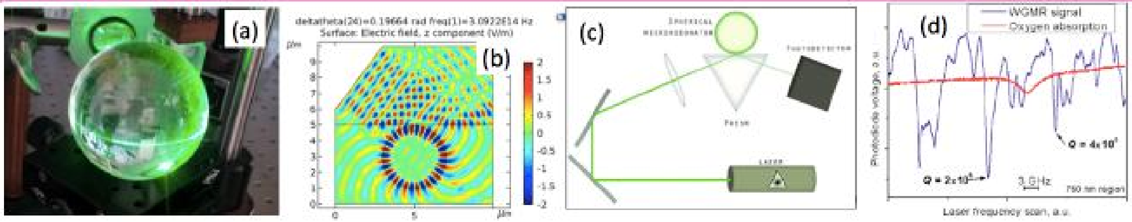
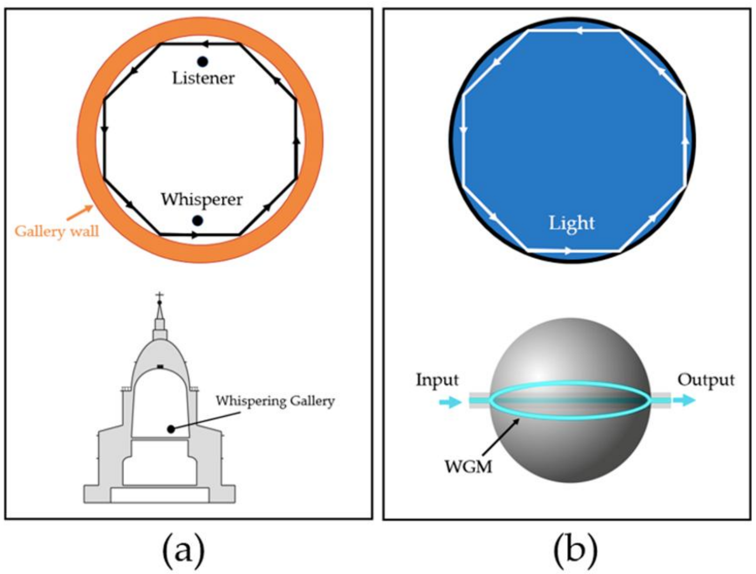
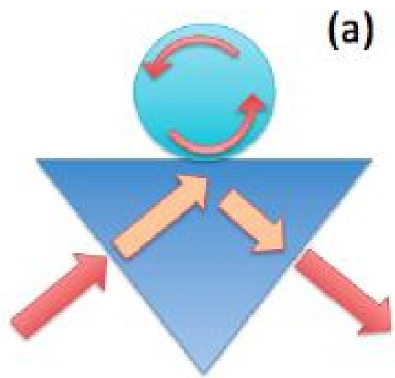
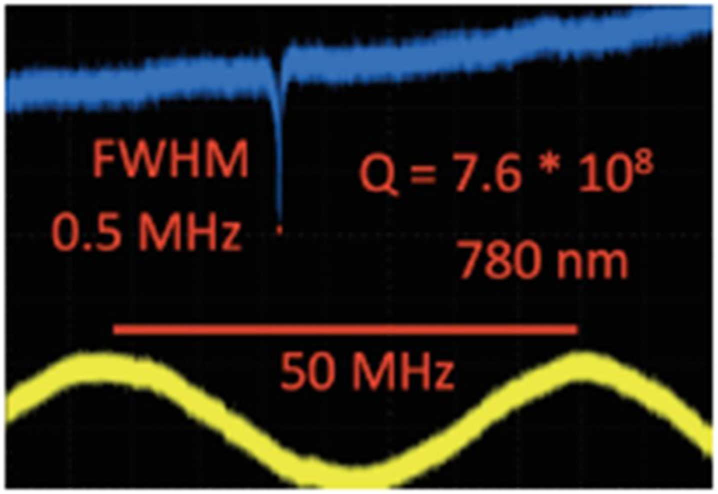


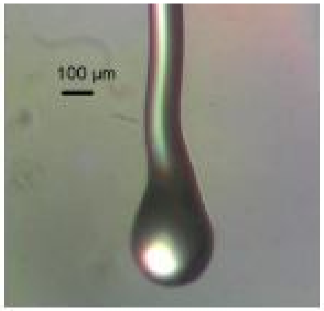
Figure 1. Optical WGM resonators. (a) macroscopic resonator used for demonstration purposes (8 cm in diameter). A light ray on the perimeter of the sphere is seen. (b) computer simulation of the light in WGM resonator, (c) general simple experimental scheme used in WGM resonator research, (d) example of WGM resonator resonances[2] (diameter of the resonator ~0.5 mm).

Research example – Whispering gallery mode resonators





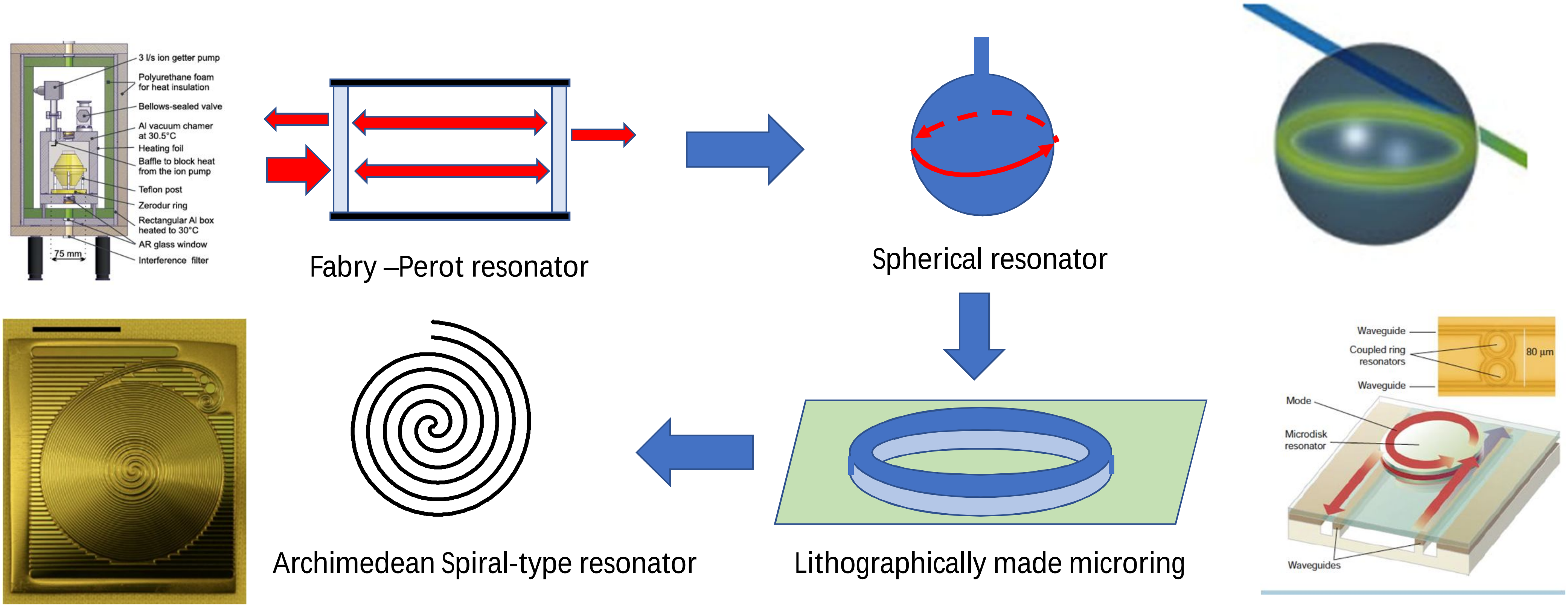




https://www.mdpi.com/1424-8220/17/9/2095

Resonance shifts from:
- Temperature
- Humidity
- Attached biomolecules

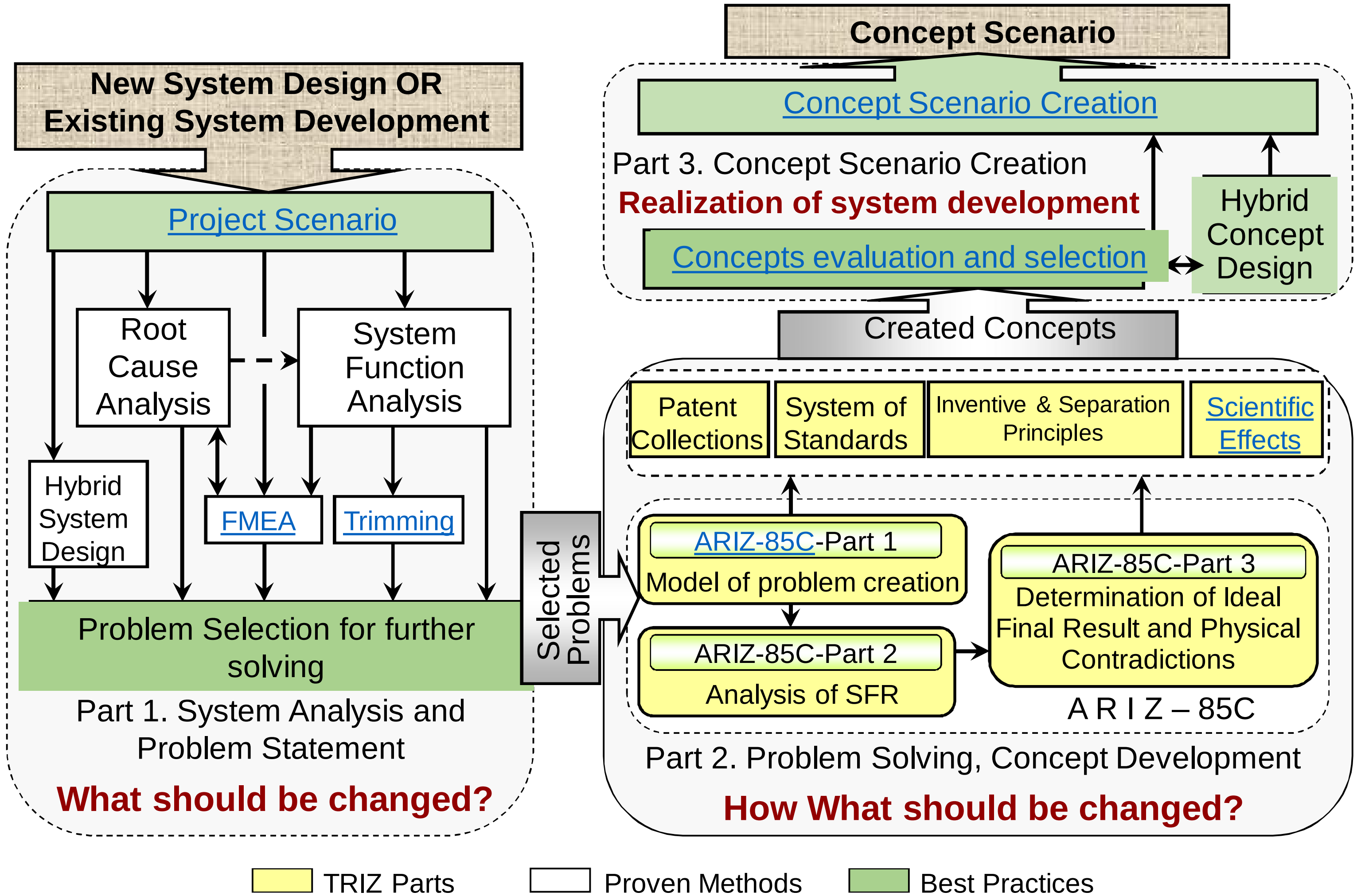
Example of scientific solutions

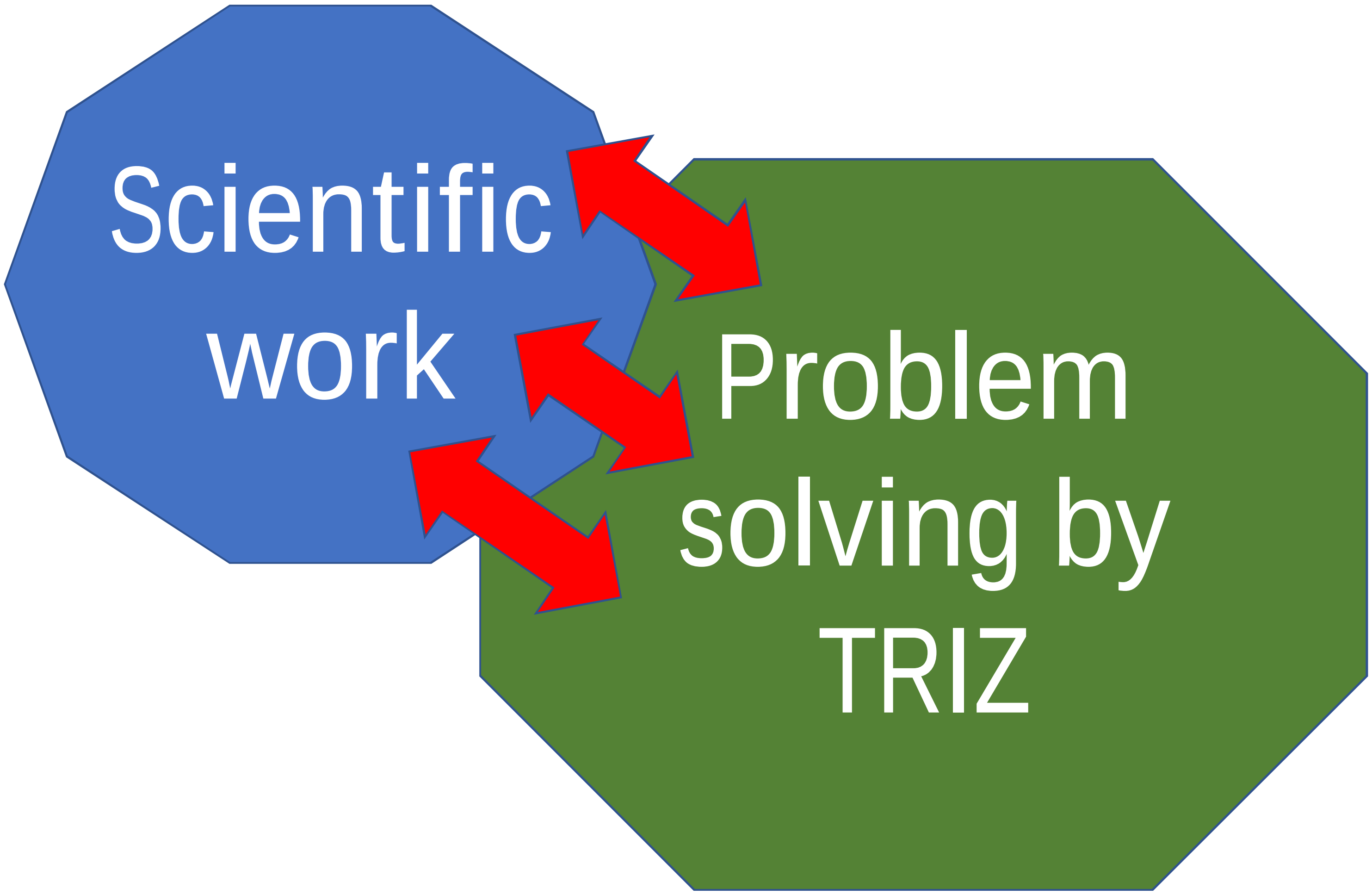


Lee, H., Suh, M., Chen, T., Li, J., Diddams, S. A., & Vahala, K. J. (2013). Spiral resonators for on-chip laser frequency stabilization. *Nature Communications*, *4*, 1–6. https://doi.org/10.1038/ncomms3468

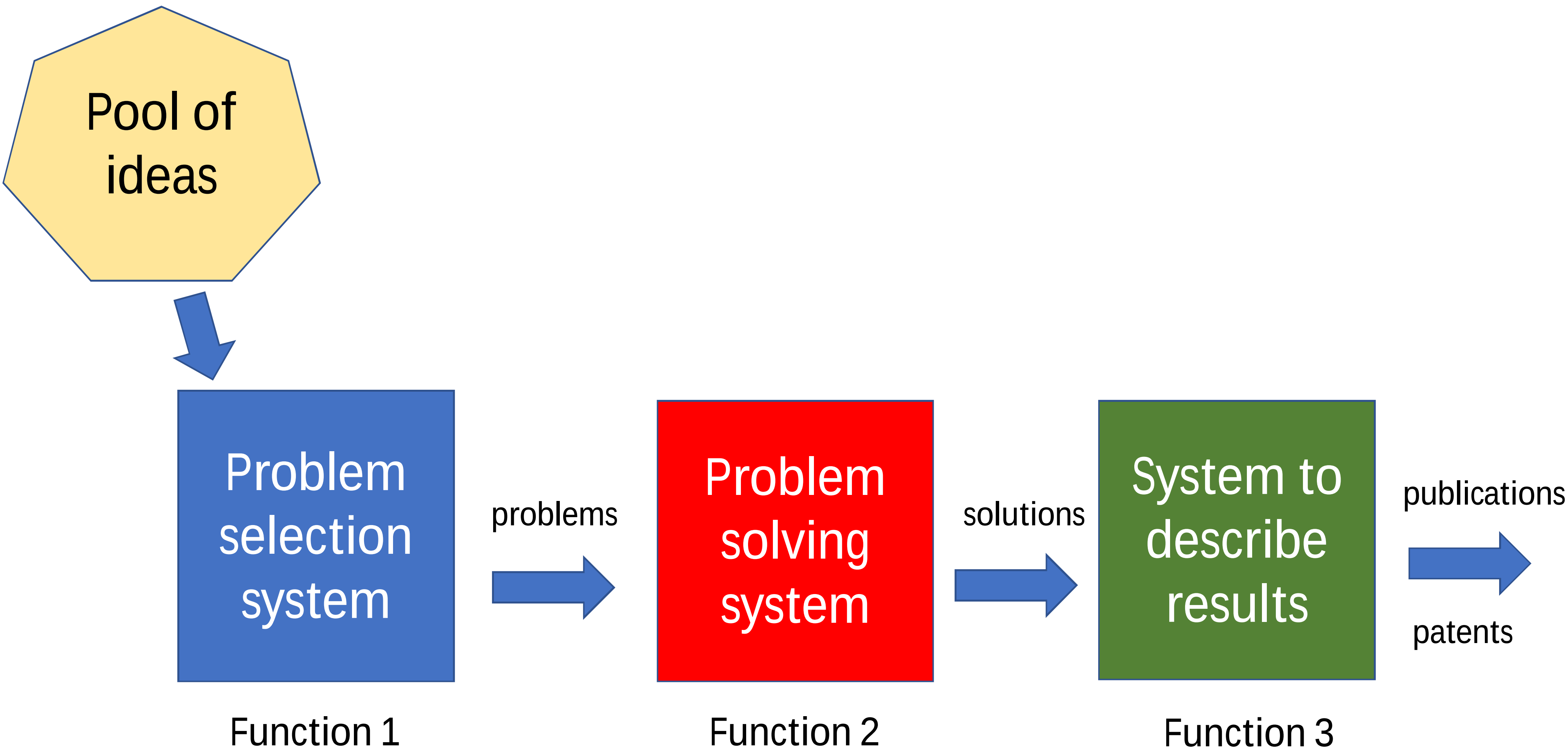
TRIZ Innovation Roadmap (I.Bukhman)

TRIZ Innovation Roadmap for Project Creation & Problem Solving
(most complete variant)



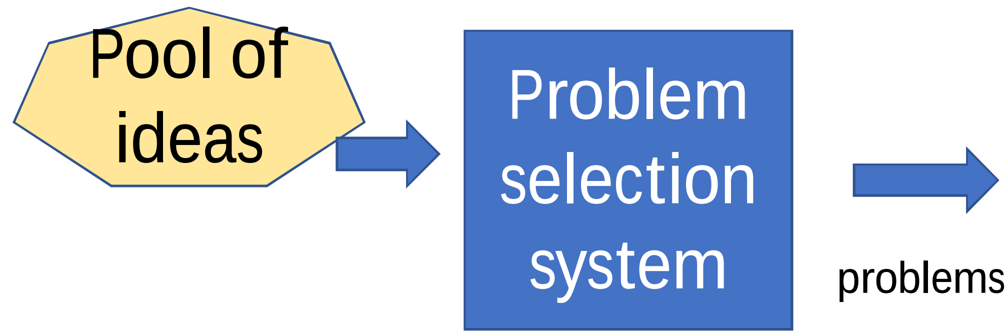

Scientific work
Problem solving by TRIZ

Scientific work flow and TRIZ advices for it

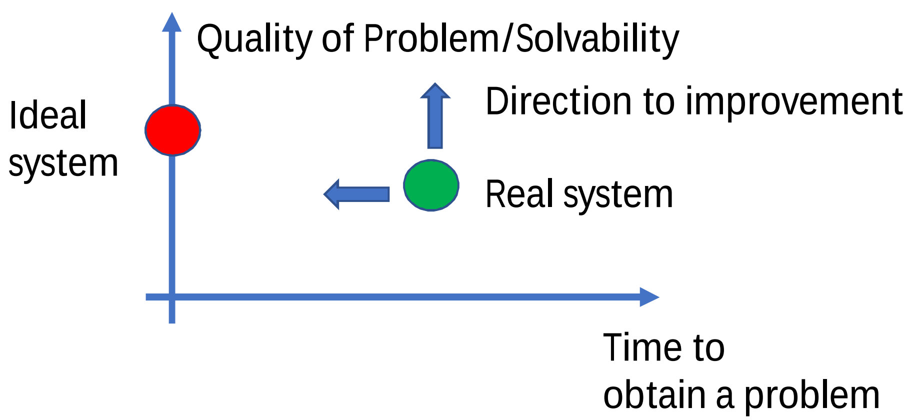


TRIZ: each system developes towards ideality

Problem selection system

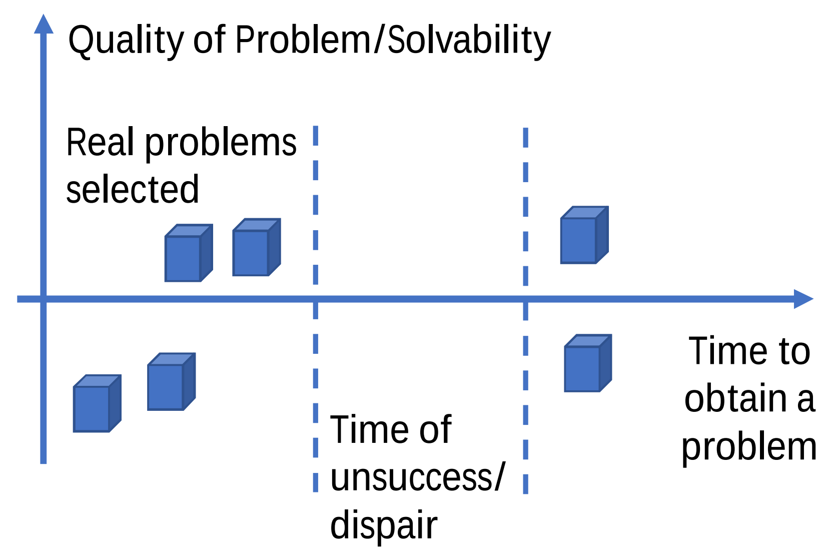


TRIZ analyses: ideality



$$\text{Ideality} = \frac{\text{Quality of Problem}}{\text{Time to obtain a problem}}$$

Current system analyses



Problem selection system

Pool of ideas

Problem selection system

problems

Hybrid system design

System 1 — Reading of scientific literature

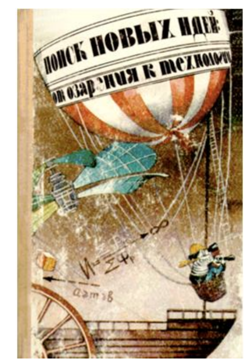
System 2 — Excellent scientists inform about problems

System 3 — Almost arbitrary/“attractive”/on a surface problem in the field

System 4 — Funders define problems

System 5 — TRIZ system analyses predicts problems

System 6 — Following, repeating what other researchers do



Laws of evolution, standards,
Lines of evolution (disretisation).

Hybrid system design

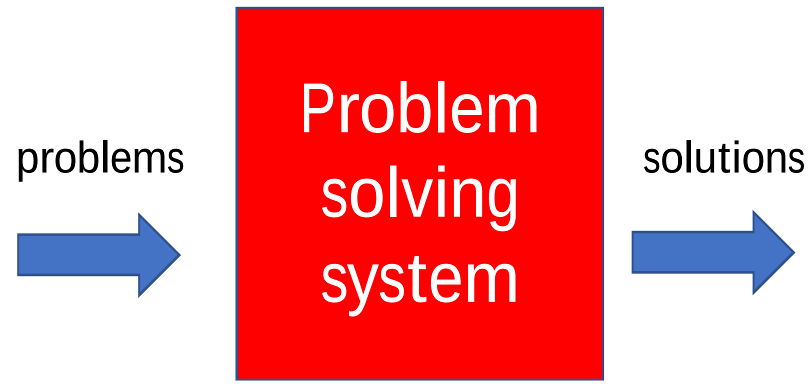
	System 1 read scientific literature	System 2 Other scientist define problem	System 3 Arbitrary problem	System 4 Funders define problem	System 5 TRIZ analyses	System 6 Repeating others
Time to get problems	- 4	- 1	3	2	1	**3**
Quality of Problems	3	2	-2	2	**4**	3
Solvability of problems	2	-1	0	1	**4**	4
Impact of Solutions	3	2	-2	**4**	**4**	1
Expected citation of solution	**4**	3	1	2	**3**	0

Select the base system – 6. Repeating others

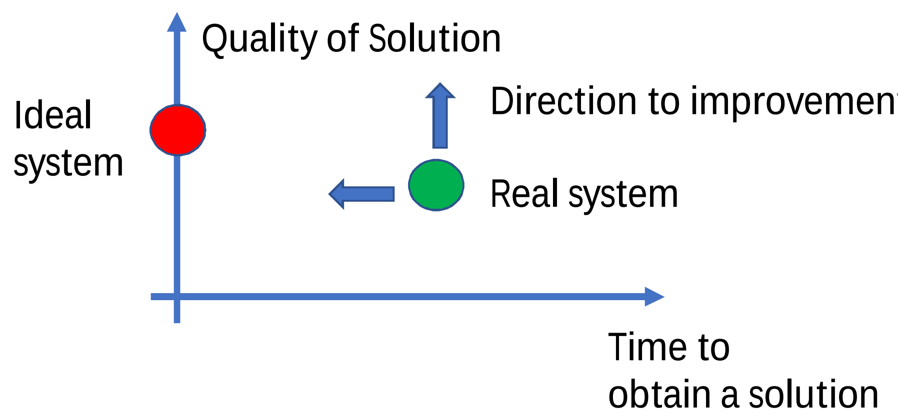
Finding how to include best aspects of other systems

System 5 inclusion is valuable

Problem solving system

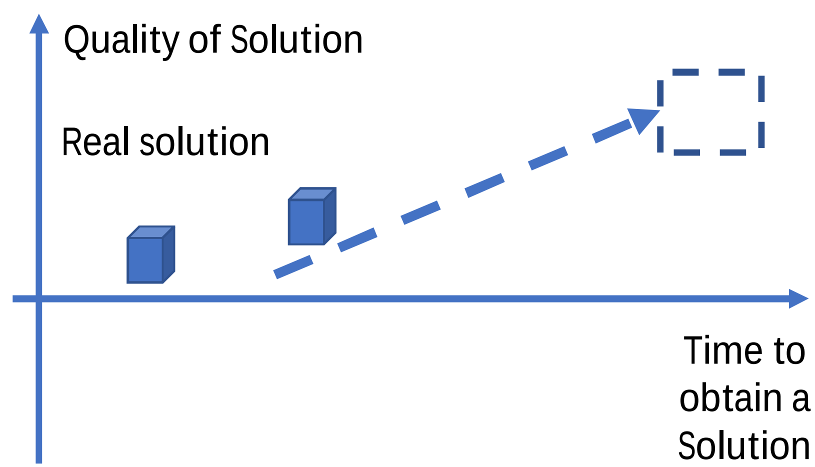


TRIZ analyses: ideality

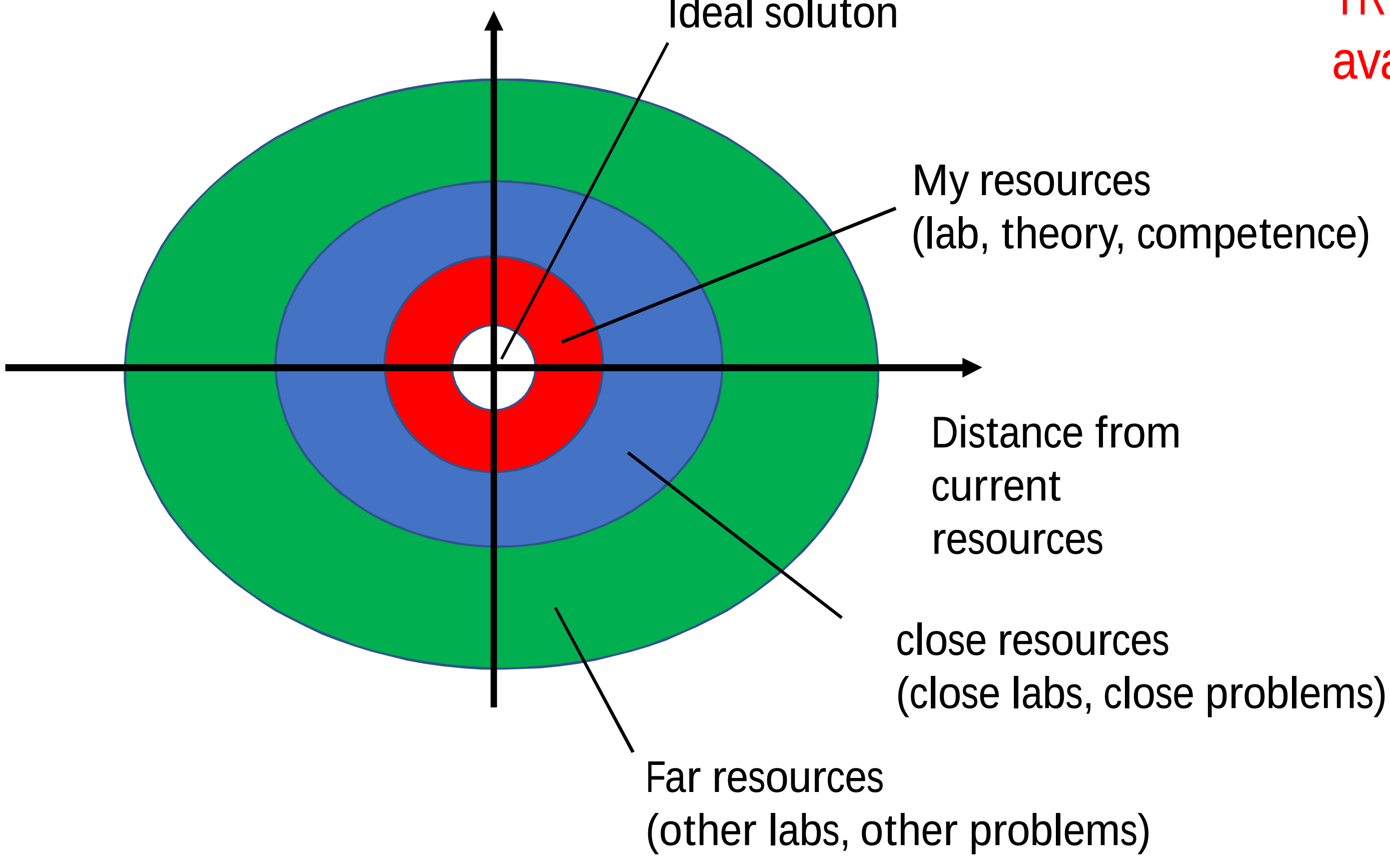


$$\text{Ideality} = \frac{\text{Quality of Solution}}{\text{Time to obtain a solution}}$$

Current system analyses

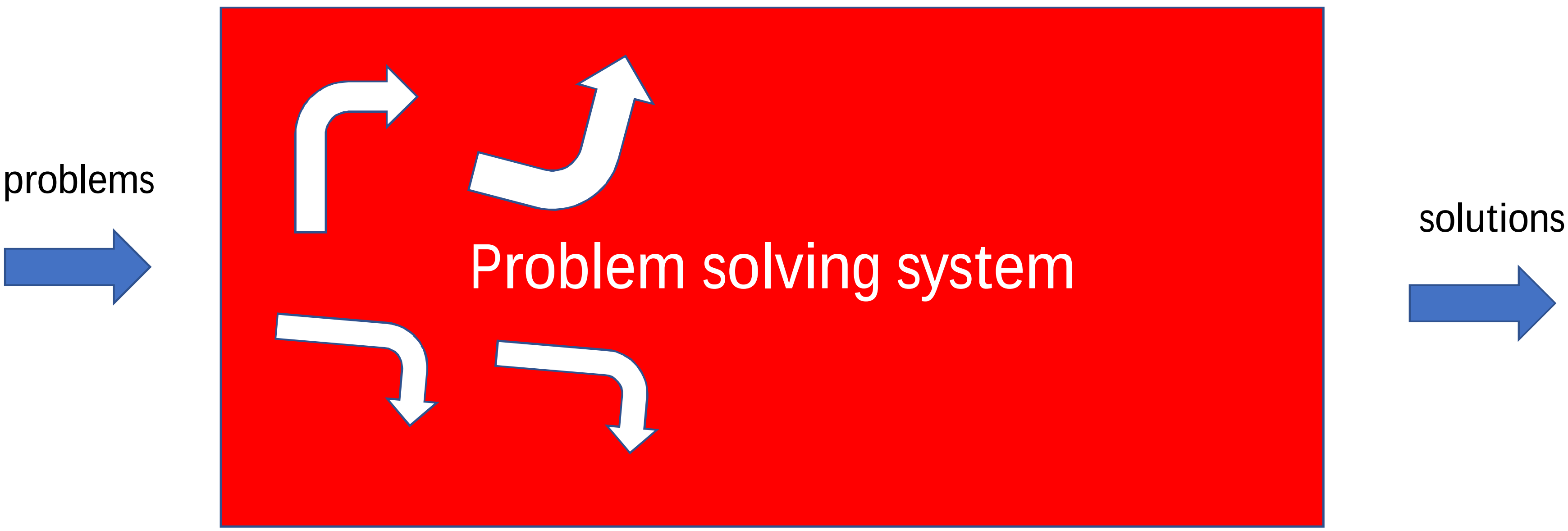


Problem Solving system



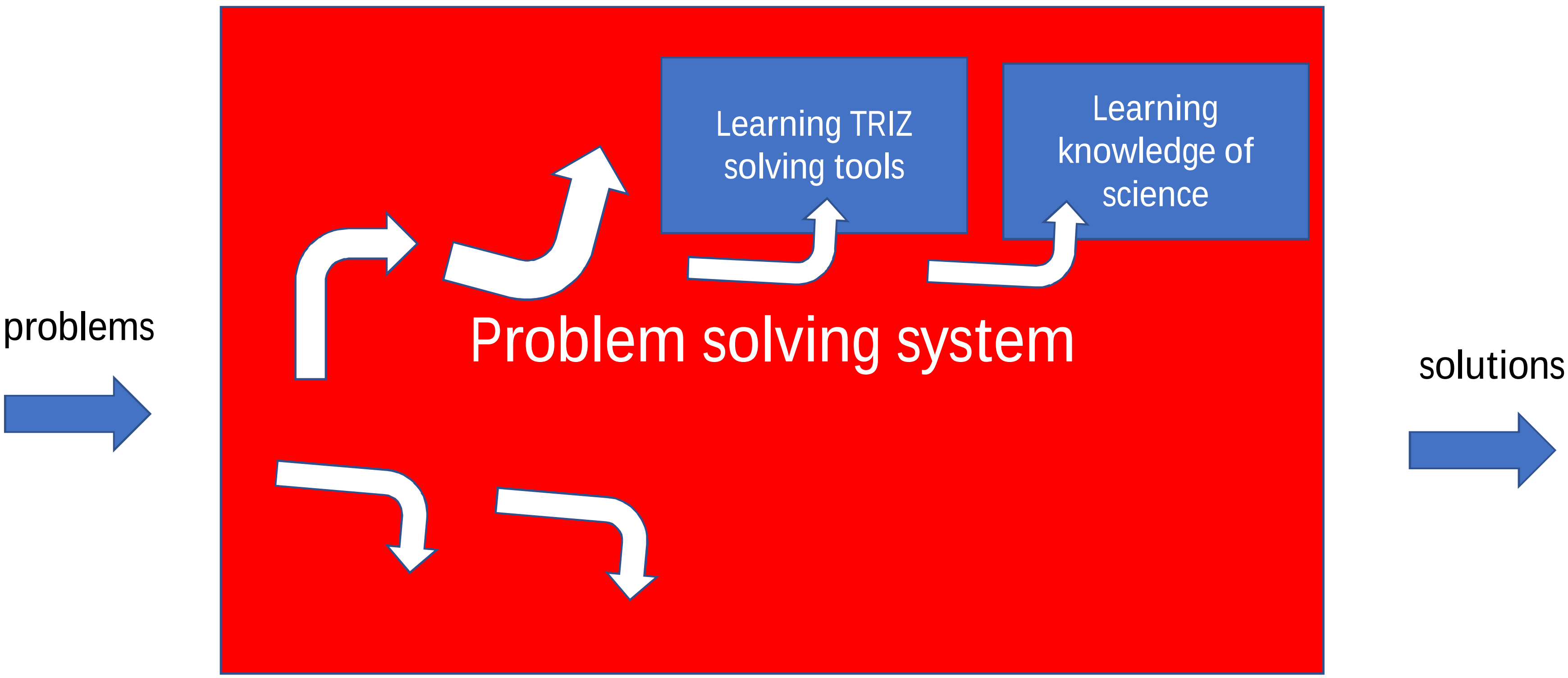
TRIZ advice: at first use available resources

Current system analyses



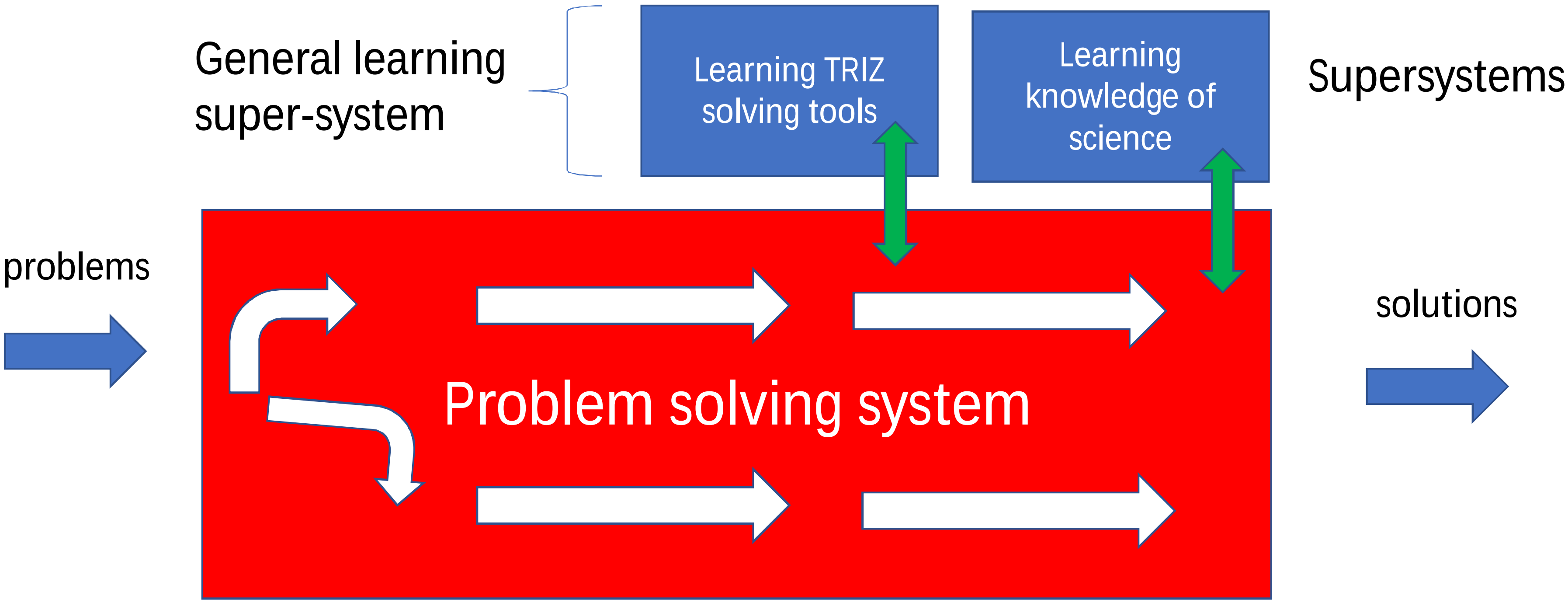
Energy dissipates and therefore does not come to solution

I analyse and analyse problems, and does not come to solution



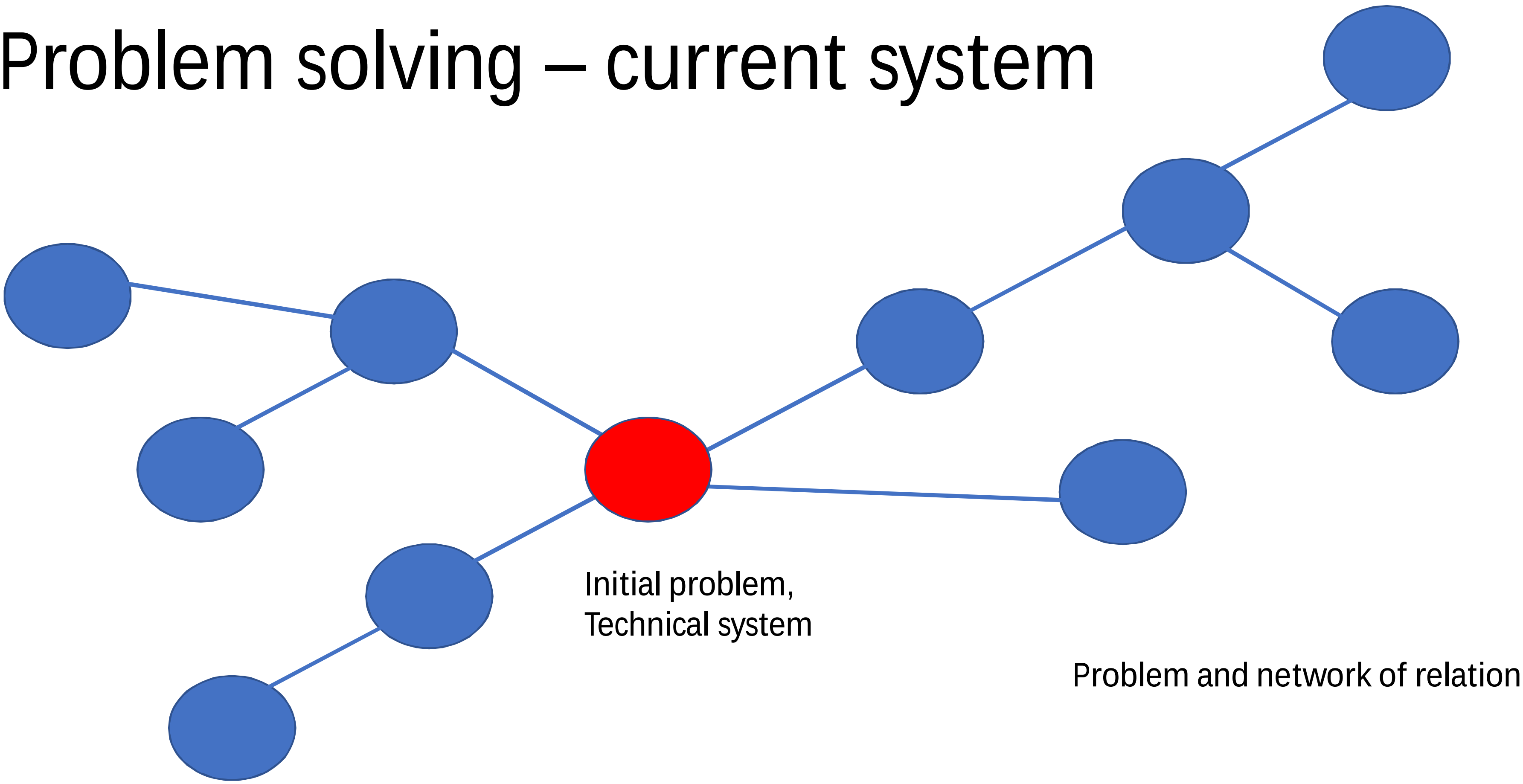
Energy dissipates and therefore does not come to solution

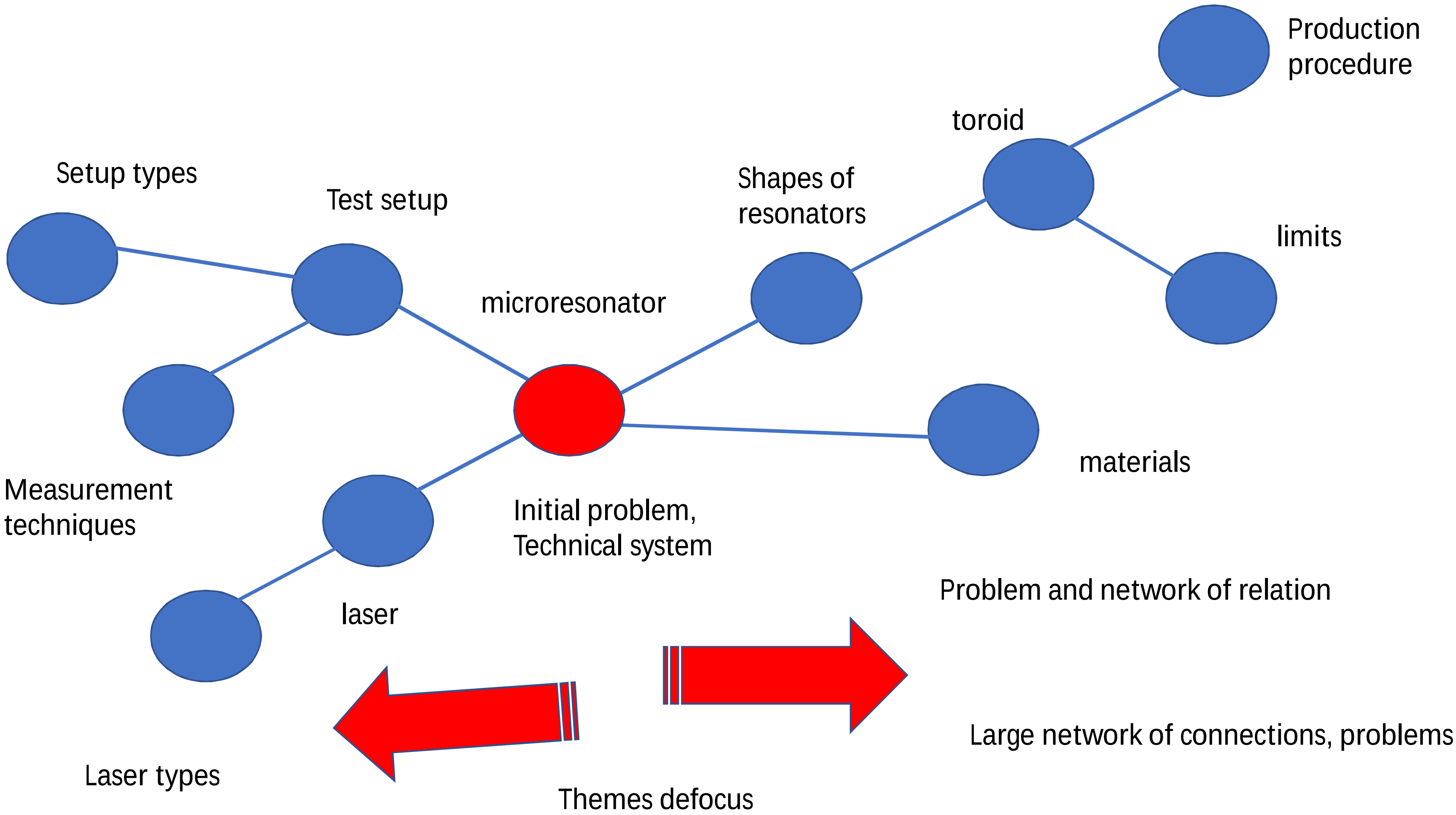
I analyse and analyse problems, and does not come to solution

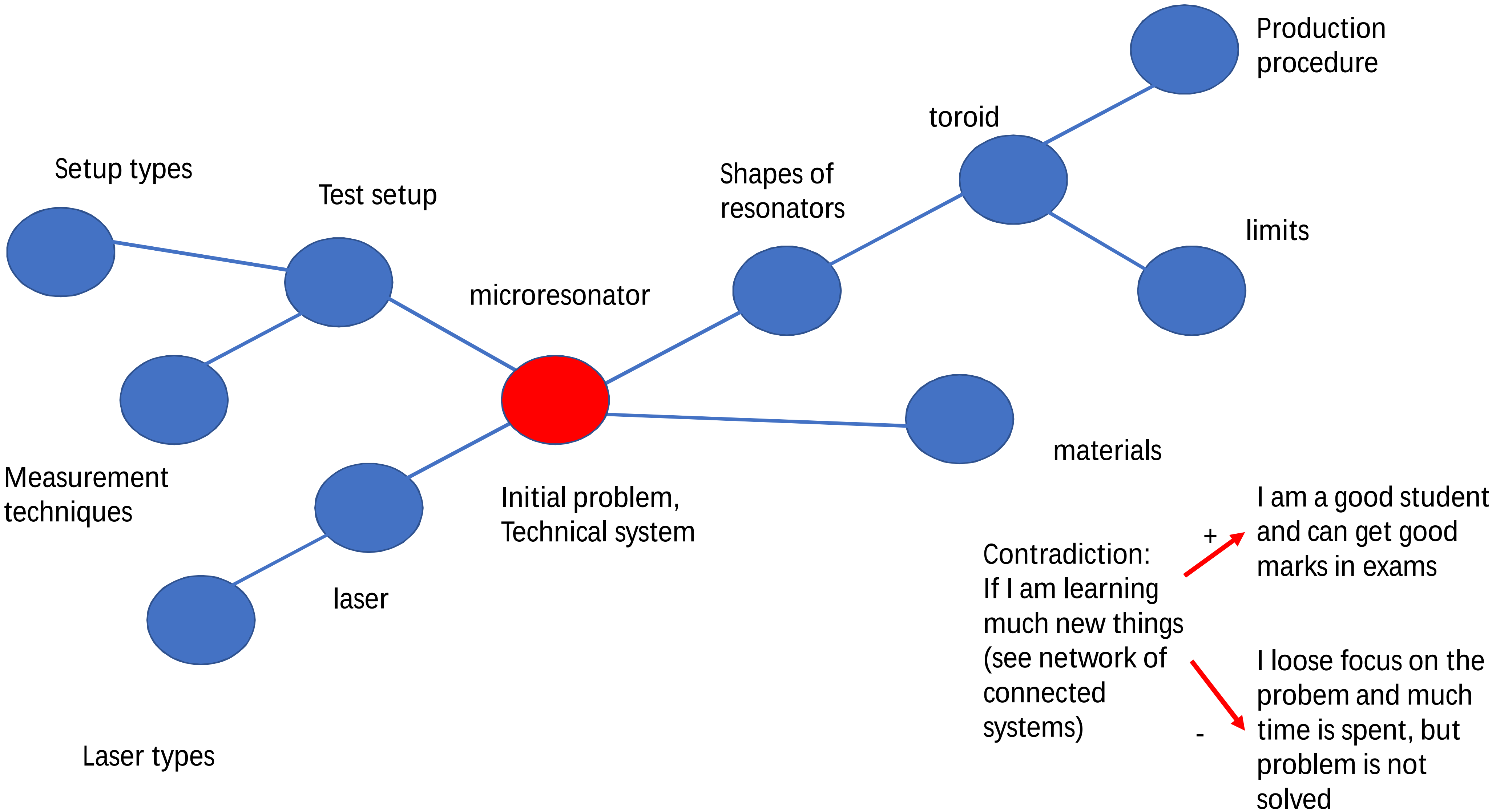


TRIZ advice: System becomes more ideal if some of its functions is realized by other systems (super-systems).

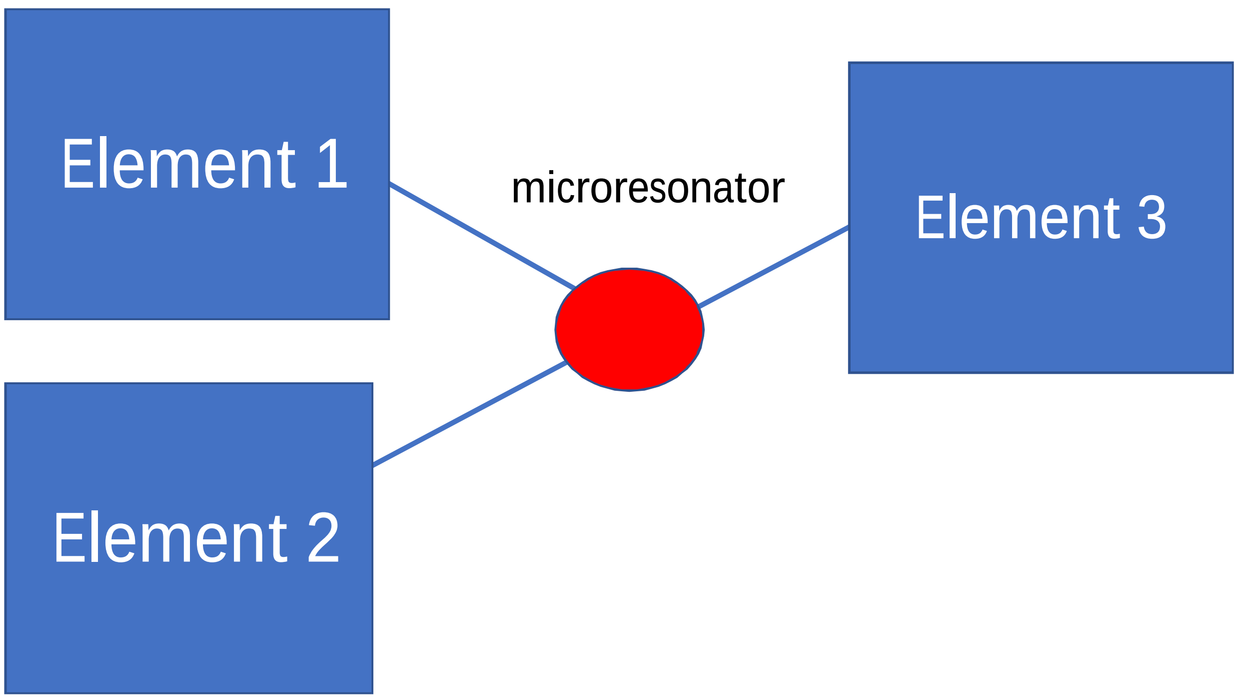
Problem solving – current system

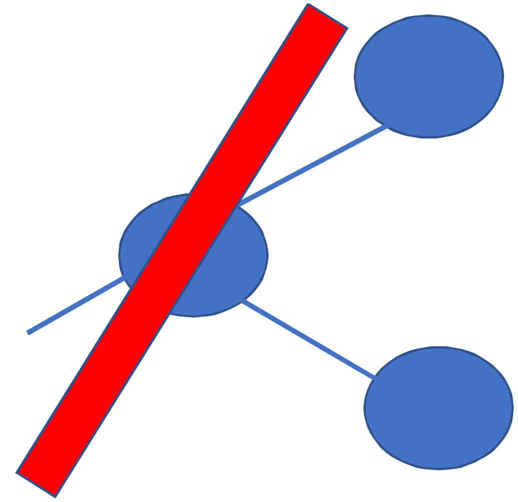



Production procedure
toroid
Setup types
Test setup
Shapes of resonators
limits
microresonator
materials
Measurement techniques
Initial problem, Technical system
Problem and network of relation
laser
Large network of connections, problems
Laser types
Themes defocus

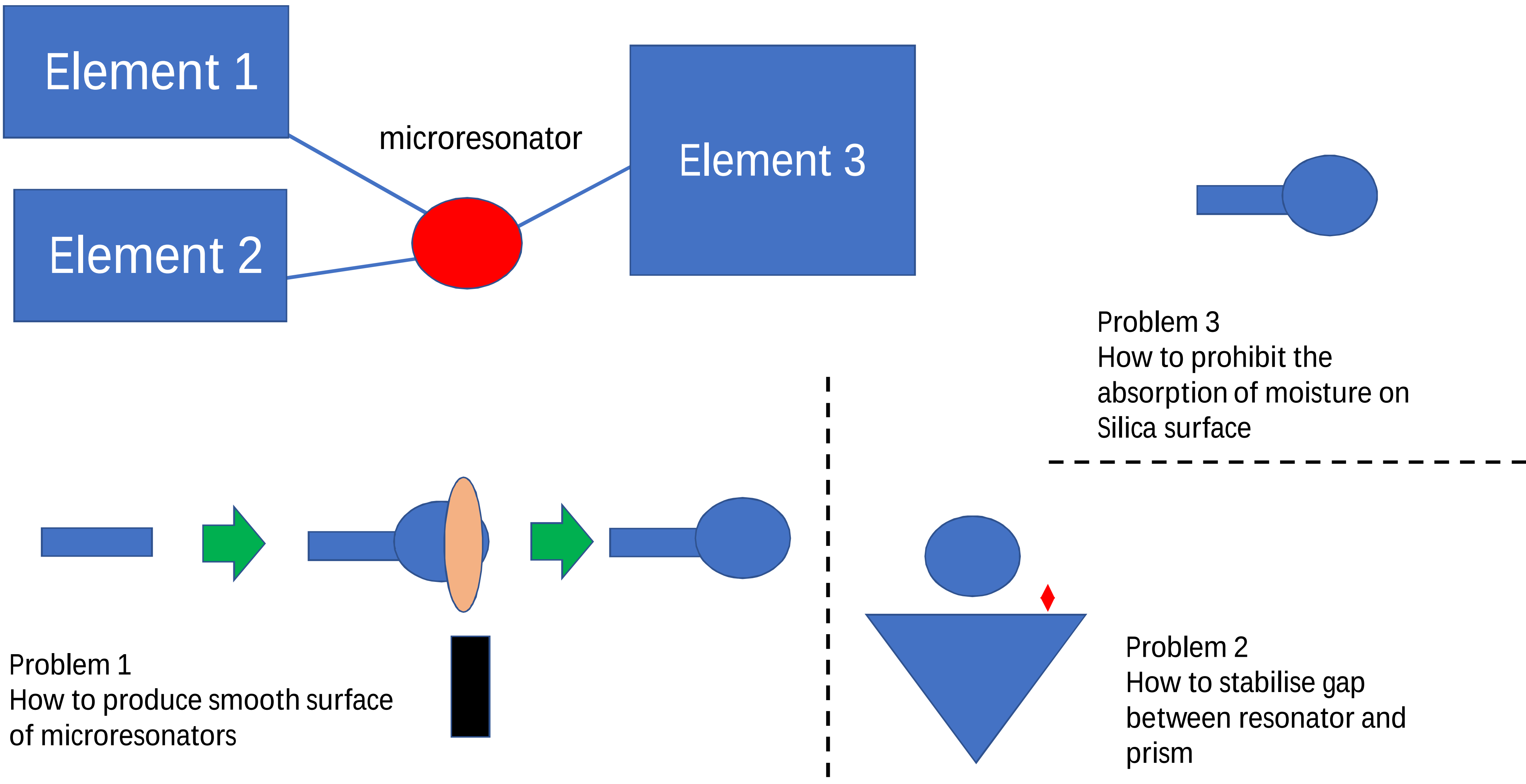

Production procedure
toroid
Setup types
Test setup
Shapes of resonators
limits
microresonator
materials
Measurement techniques
Initial problem, Technical system
laser
Laser types
Contradiction: If I am learning much new things (see network of connected systems)
+
I am a good student and can get good marks in exams
-
I loose focus on the probem and much time is spent, but problem is not solved

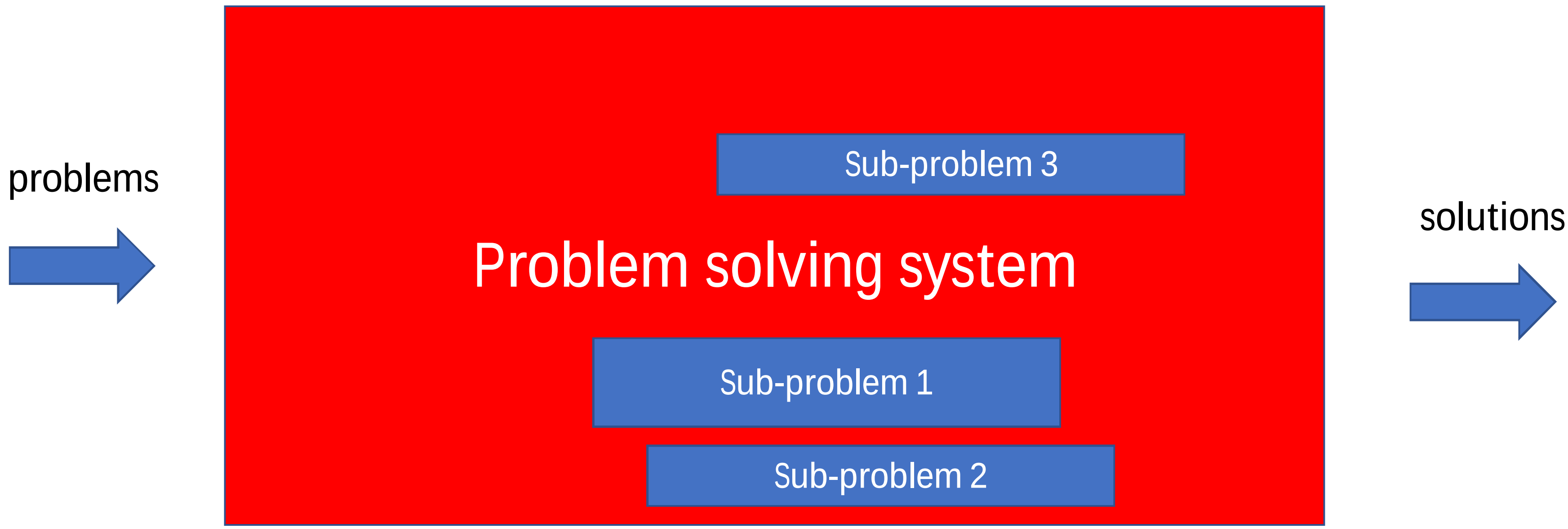
TRIZ advice: formulate compact problem - contradiction, Substance Field notion (Standards)





TRIZ advice: formule compact problem - contradiction, Substance Field notion (Standards)

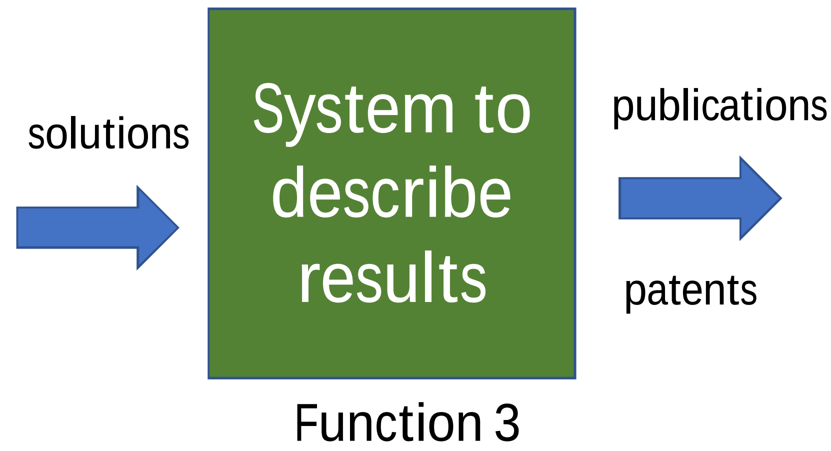




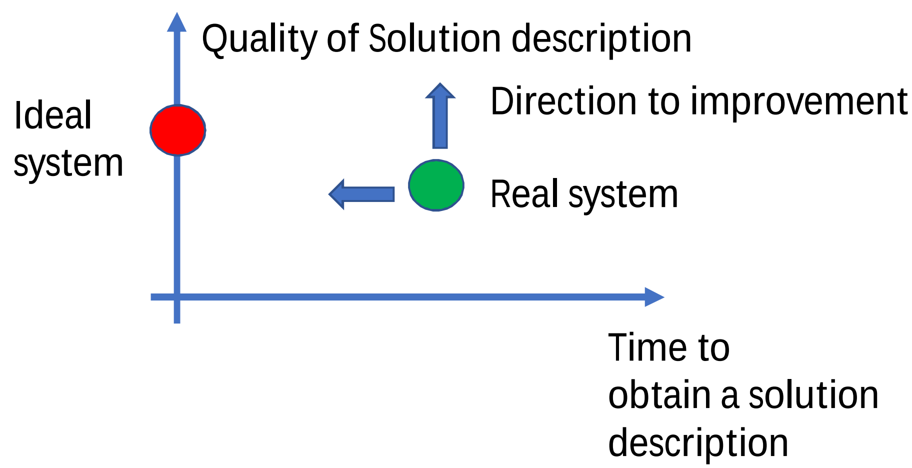
TRIZ tools to solve problems:

- Ideality principle
- Laws of system development
- ARIZ
- System of Standards
- Elimination of System (Technical) Contradictions
- Physical effects
- and other

Solution Description system

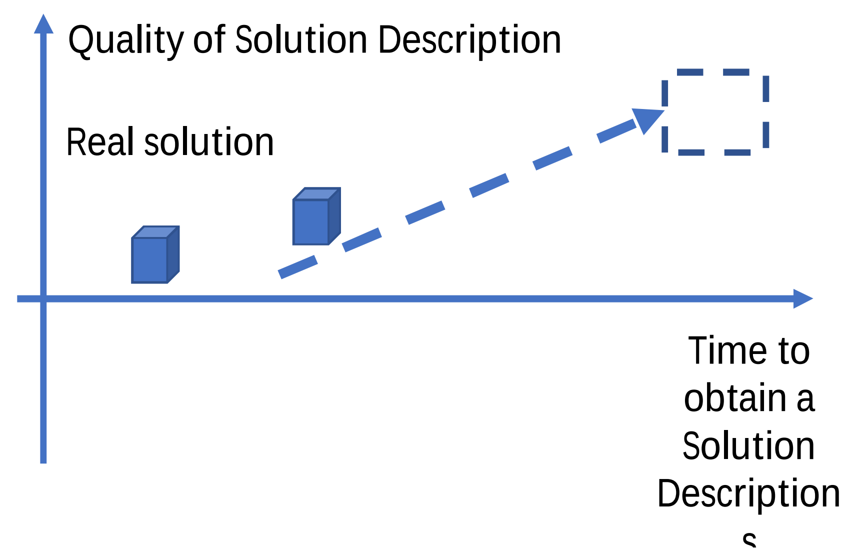


TRIZ analyses: ideality

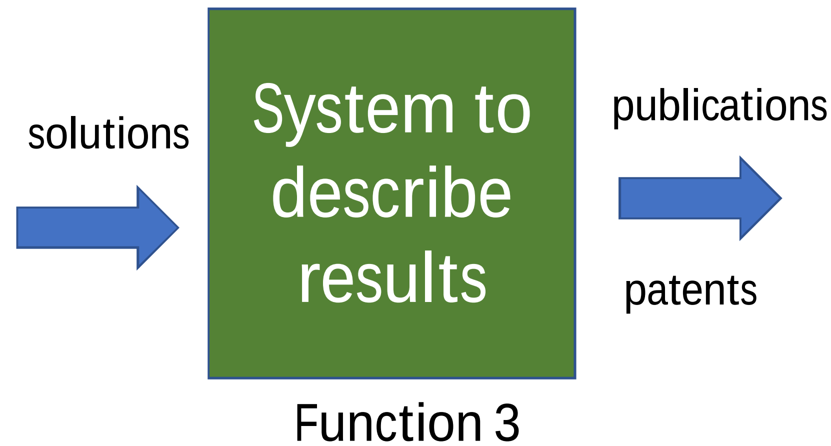


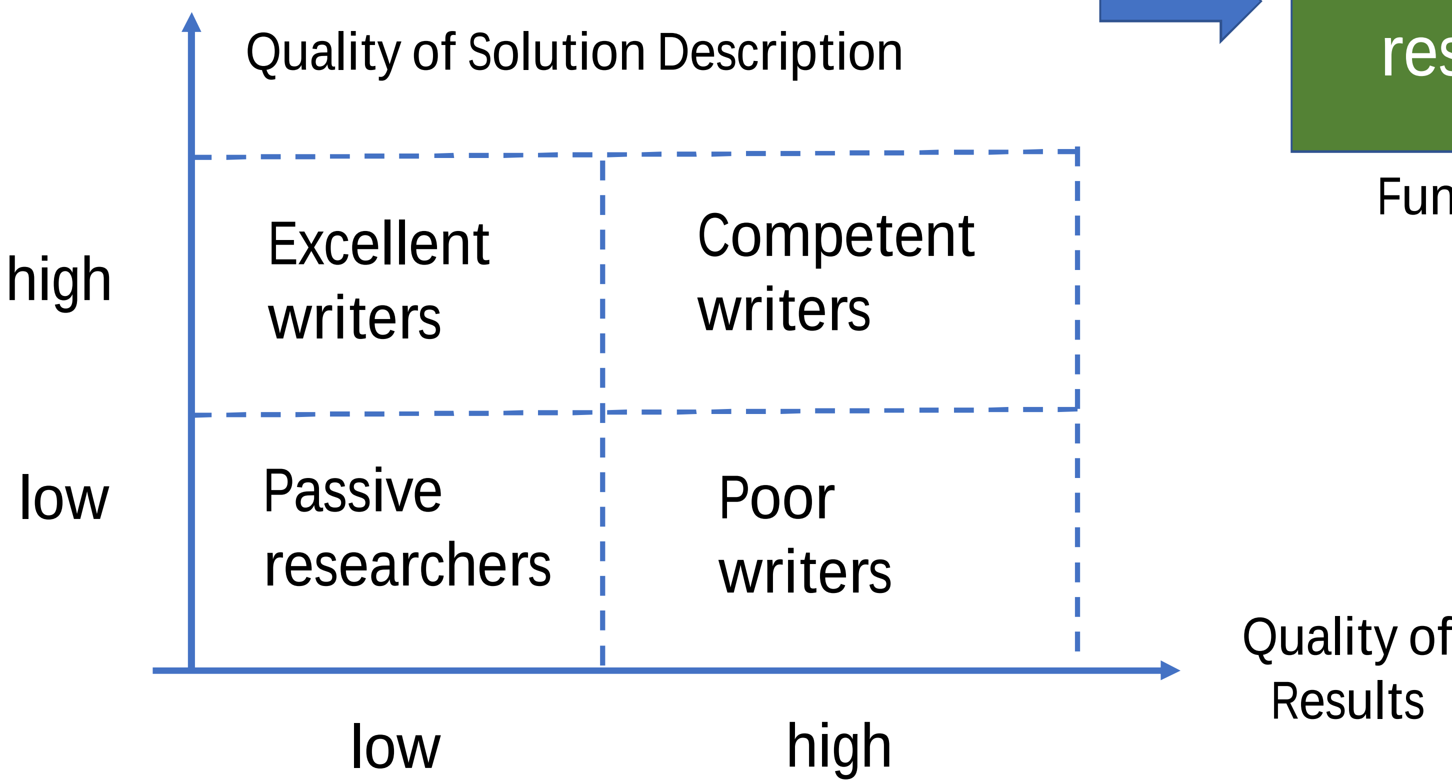
$$\text{Ideality} = \frac{\text{Quality of Solution Decription}}{\text{Time to obtain a solution description}}$$

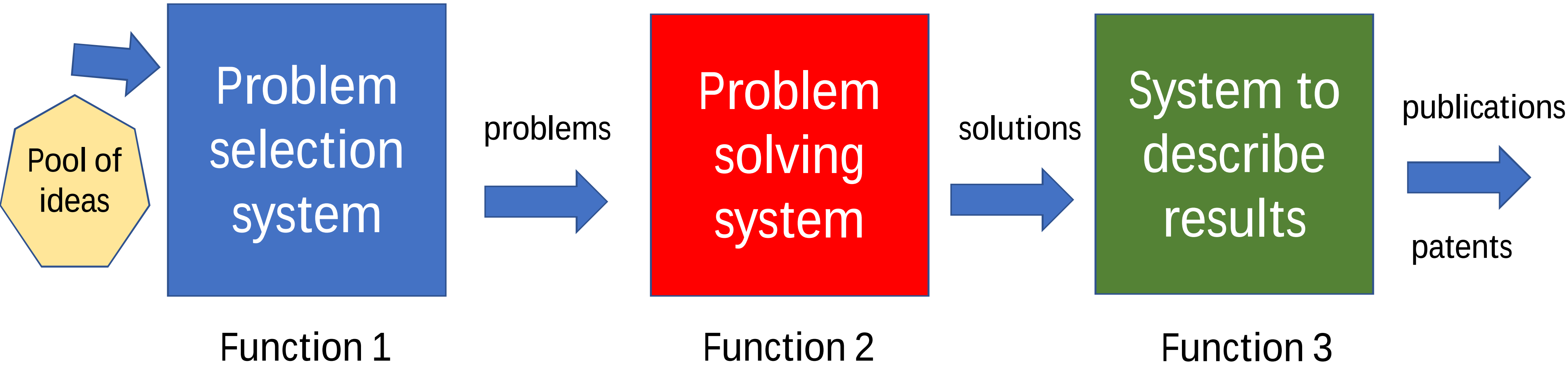
Current system analyses



Solution Description system







TRIZ incorporation:
- minimal system
- Hybrid System
- Laws of System Development
- Lines of System development

TRIZ incorporation:
- Solving technical problems by using all elements of TRIZ

TRIZ incorporation:
- minimal system

Roadmap for TRIZ Application in Research projects