On Generation of New Ideas for PhD Research in Computer Science and Engineering

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1. Introduction

This paper represents an effort to help PhD students in computer science and engineering to generate good original ideas for their PhD research. Our effort is motivated by the fact that most of PhD students demonstrate an eager desire to get guided by an appropriate methodology: (a) If one types “best method” at Google, one obtains about one million hits, and a research generation methodology oriented paper is the hit#1; (b) If one types “good method” at Google, one obtains about one billion hits, and a research presentation methodology paper is hit#1. This situation lasts for about one decade now.

2. Relevant Studies

This paper is a follow up of four previous papers on different aspects of research generation methodology [Milutinovic95 and Milutinovic2008] and research presentation methodology [Milutinovic96 and Milutinovic2012]. In addition, this paper builds on the top of 10 other representative studies related to methodologies for research innovation in science and engineering [Cummings2005, Faulkner94, Iivari2007, Kline86, Libarkin2002, Linn87, Pavon2005, Perkmann2007, Swan97, Wang2003], and tries to transform existing innovations into an original set of 10 different methodological approaches to innovation in computer science and engineering.

3. Classification

This section, together with Figure 3.1, defines the essence of 10 different methods that can be used to generate new R+D ideas in computer science and engineering.

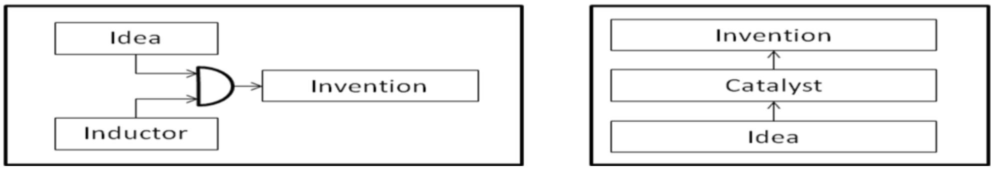
Mendeleyevization: Inductor versus Catalyst (M1 vs M2)
If one of the classification classes includes no examples, it first has to be checked why is that so. If it is so because it makes no sense, an appropriate explanation is in place. If it is so because the technology or the applications are not yet ready for such an approach, one can act in the same way as the famous chemists Mendeleyev: empty positions in any classification are potential avenues leading to new inventions. As indicated in Figure A, these inventions sometimes need an inductor (a resource that makes an invention happen) or a catalyst (a resource that turns a known invention without potentials into an invention with potentials). We refer to such an approach as: Mendeleyevization.

Hybridization: Symbiosis versus Synergy (H1 vs H2)
Sometimes two classification classes can be combined, in order to obtain a hybrid solution (hybridization). Hybrid solutions can be symbiotic (measuring the conditions in the environment and switching from one approach to the other, so that each approach is active all the time while the conditions are such that it provides better performance compared to the other approach) or synergistic (creating a new approach, which, for each particular solution element takes the better solution element of two different approaches). This is shown in Figure B. The assumption here is that one solution is better under one set of conditions, and the other solution is better under another set of conditions. Another assumption is that solution elements of one solution are better in one domain and that solution elements of another solution are better in another domain.

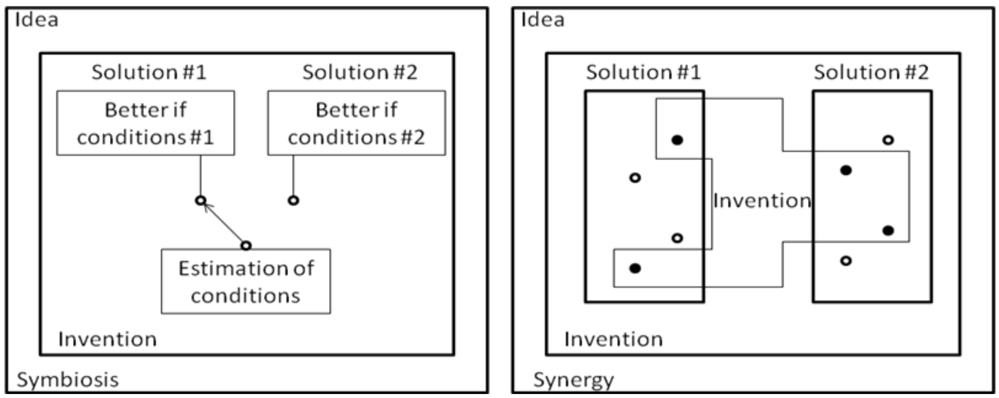
Transdisciplinarization: Modifications versus Mutations (T1 vs T2)
Often times, good new ideas get generated if algorithms, procedures, ways of thinking, or philosophies of thinking can be ported from one field to another field, along the lines of transdisciplinary research methodologies (transdisciplinarization). As indicated in Figure C, for an idea to work better in the new field, either smaller modifications or larger mutations have to be introduced. Mutation means that analogy is used to generate a new idea.

Remodelling: Granularization versus Reparametrization (R1 vs R2)
Sometimes it is simply the best to take a research direction different (even opposite) compared to what others take (retrajectorization via remodeling). The different (opposite) research direction makes sense either if a more detailed set of parameters is in place (granularization, due to model changes because of application changes), or because parameters of the environment have changed permanently (reparametrization, due to model changes because of technology changes), as indicated in Figure D. The two alternatives are referred to as granularization and reparametrization.

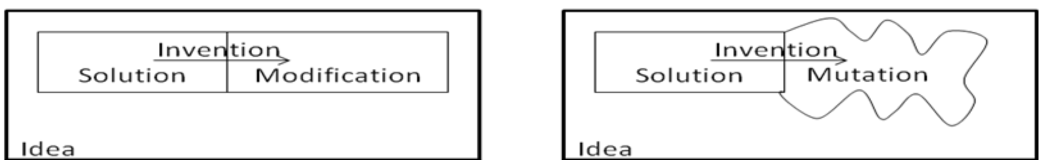
Unorthodoxization: ViewFromAbove versus ViewFromInside (U1 vs U2)
This category encompasses the approaches that are difficult to classify (Figure E): Sometimes one sees something that others did not see for decades or centuries (ViewFromAbove) or one gets stroked by an idea of a genius with no ground in existing research (ViewFromInside).



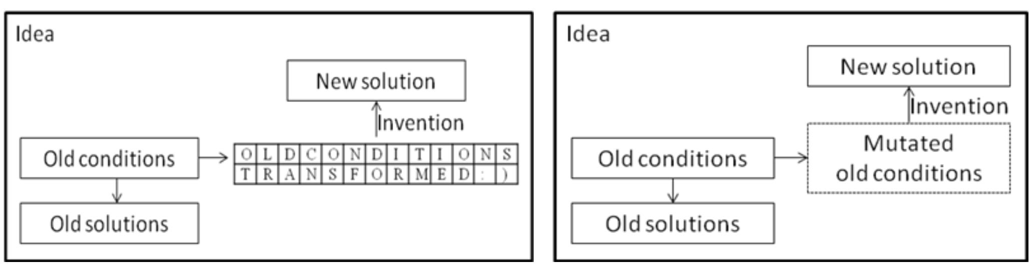
A: Mendeleyevization (Inductor versus Catalyst) – M1 vs M2



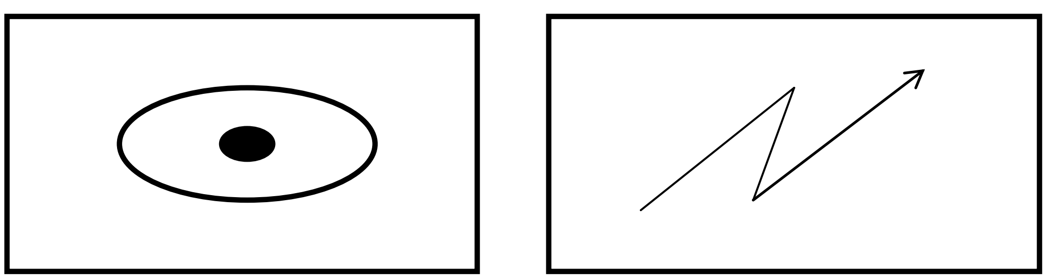
B: Hybridization (Symbiosis versus Synergy) – H1 vs H2



C: Transdisciplinarization (Modification versus Mutation) – T1 vs T2



D: Remodeling (Granularization versus Reparametrization) – R1 vs R2



E: Unorthodoxization (ViewFromAbove versus ViewFromInside) – U1 vs U2

Figure 3.1: Symbolic Representations of Ten Idea Generation Methods.
The symbolic explanations are meant to be intuitive.

4. Popular Examples

This section sheds more light on 10 different idea generation methods introduced in this paper.

This section sheds more light on 10 different idea generation methods introduced in this paper. Examples are given from a course on research innovation taught for several years now at the University of Belgrade.

As far as M1/M2, the famous classification of computer systems by Mike Flynn (SISD, SIMD, MISD, MIMD) initially included no examples of the MISD type. Later on, a DFT machine was categorized as an MISD machine [Milutinovic86A], as well as one pipelined machine [Milutinovic87C]; DFT served as an indictor and pipeline as an catalyst. Other popular examples are related to various signal processors and process accelerators.

As far as H1/H2, the essence of [Milutinovic85] is that two algorithms are combined into one on the either-one-or-the-other basis, and on a combine-inherent-details basis in [Milutinovic87B]. Other popular examples include hybrid computers or computers that use special purpose accelerators, when appropriate data/process patterns are located.

As far as T1/T2, [Milutinovic86B] ports algorithms from Silicon to GaAs, and introduces appropriate modifications along the process, while [Milutinovic87A] creates a proposal for a novel computer architecture, along the analogies with a biological honeycomb. Other popular examples include porting of the FFT from seismic engineering to signal processing, or introduction of mathematical neural networks inspired by biological neural networks.

As far as R1/R2, [Milutinovic88] offers a new algorithm that makes sense if an environment is represented with a more detailed model, while [Milutinovic89] offers a new solution in a changed environment, when a design has to be ported from Silicon to GaAs. Other popular examples are related to concept modeling in AI based on graphical representation with icons (in a model with few icons, one can make a conclusion which is different, and often times even opposite, compared to a conclusion made from a model with a much larger number of icons); also, when the environment changes (for example, the ratio of processing speed to communication speed changes), a different type of supercomputing network becomes optimal.

As far as U1/U2, [Milutinovic2000] generates an innovation after trying to make a holistic view, and [Milutinovic2001] introduces an idea after an effort is made to understand the intrinsic details of the problem. Other popular examples include the contributions of Nobel Laureates Martin Perl and Jerome Friedman.

5. Examples from the Nobel Laureate Research

This section classifies 10 different Nobel Prize achievements and classifies them into the 10 idea generation methods introduced in this paper. The summary is given in Figure 5.1.

Innovation in [Arrow] seams to have been created predominantly along the lines of the method U1. Likewise, innovation in [Cooper] corresponds to H, innovation in [DeGennes] to M2, innovation in [Friedman] to H1, innovation in [Glashow] to U1, innovation in [Kroto] to U2, innovation in [Maskin] to T1, innovation in [Perl] to U2, innovation in [Richardson] to T2, and innovation in [Wilson] to U1.

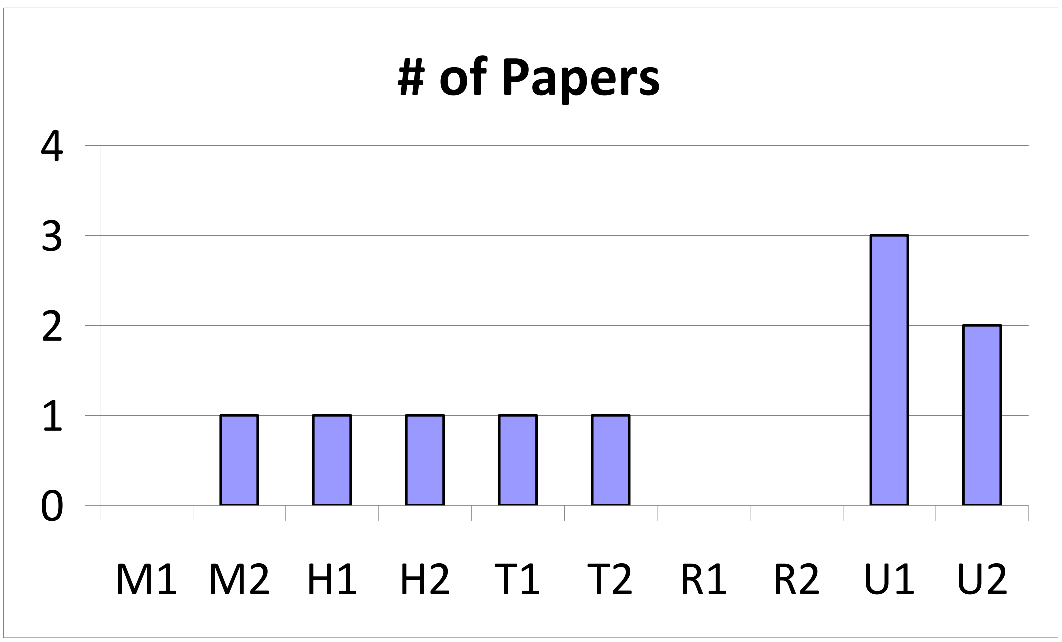


Figure 5.1. Number of Nobel Prizes based on the given innovation method.

6. Examples from von Neumann Medals

The Turing award is treated as “the Nobel Price of computing”. For the first 10 single recipients, in the text to follow, we paraphrased the contribution for which they were awarded, and based on our study, we labeled each contribution as far as the innovation method that prevailed (see the mnemonic in the parenthesis). The summary is given in Figure 6.1.

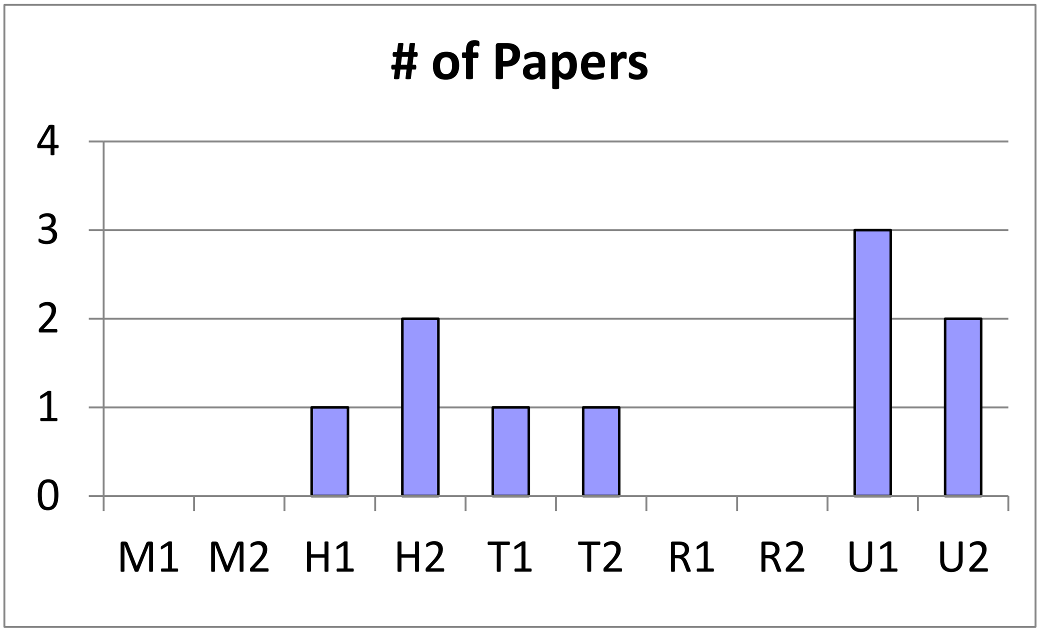


Figure 6.1. Number of von Neumann Medals based on the given innovation method.

1966: Alan J. Perlis was awarded for his influence in the area of advanced programming techniques and compiler construction.

1967: Maurice V. Wilkes was awarded as the builder and designer of the EDSAC, the first computer with an internally stored program.

1968: Richard Hamming was awarded for his work on numerical methods, automatic coding systems, and error-detecting and error-correcting codes.

1969: Marvin Minsky was awarded for artificial intelligence.

1970: James H. Wilkinson was awarded for his research in numerical analysis to facilitate the use of the high-speed digital computer.

1971: John McCarthy was awarded for the lecture “The Present State of Research on Artificial Intelligence”.

1972: Edsger W. Dijkstra was awarded as a principal contributor in the late 1950s to the development of the ALGOL, a higl level programming language wich has become a model of clarity and mathematical rigor.

1973: Charles W. Bachman was awarded for his outstanding contributions to database technology.

1974: Donald E. Knuth was awarded for his major contributions to the analysis of algorithms and the design of programming languages, and in particular for his contributions to “The Art of Computer Programming” through his well-known books.

1977: John Backus was awarded for profound, influential, and lasting contributions to the design of practical hig-level programming systems, notably through his work on FORTRAN.

7. Examples from the List of Top 500 Computer Scientists of the World

We analyzed the most referenced paper of the best ranked 100 computer scientists from the list of Top500 Computer Scientists of the World, maintained at UCLA. The summary is given in Figure 7.1.

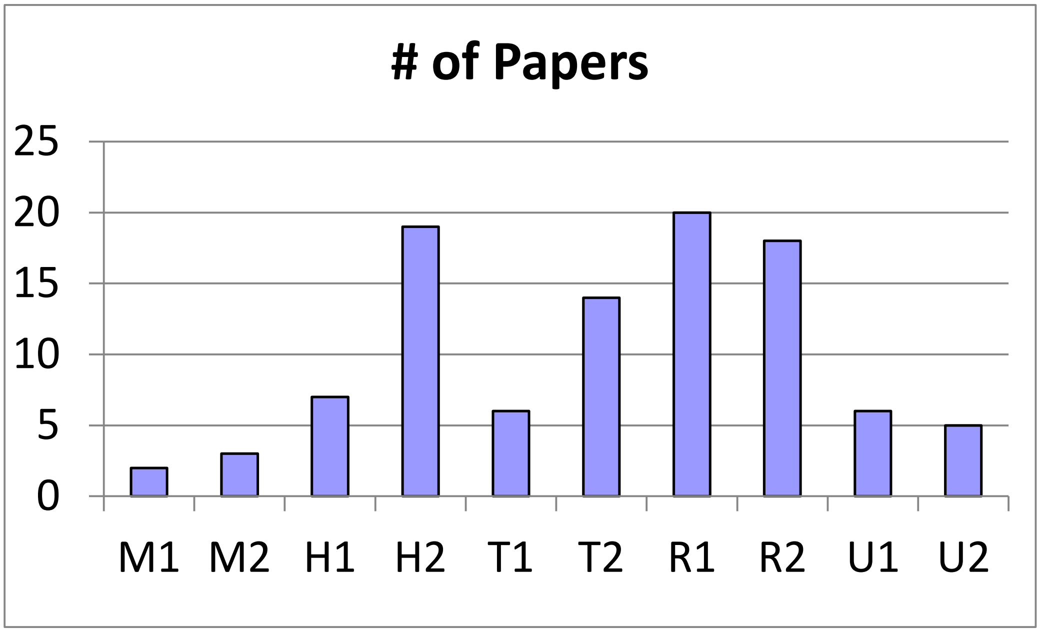


Figure 7.1. Distribution of innovation methods in the best papers of the top 100 computer scientists of the world.

8. Numerical Values from Google Scholar (distribution of 10 methods in top 10 papers of 10 different fields)

This section presents the distribution of presented innovation methods in the top 10 most referenced research papers (excluding surveys and tutorials, as well as papers on simulation-based or mathematics-based comparisons of existing approaches) for 10 different research fields, as determined by the authors of this study.

An author opinion analysis for the field of information systems (Google: “information systems”) gives the distribution is presented in Figure 8.1. For the field of optimizing compilers (Google: “optimizing compilers”) the distribution is presented in Figure 8.2. For the field of database technology (Google: “database engineering”) the distribution is presented in Figure 8.3. For the field of interconnection networks (Google: “interconnection networks”) the distribution is presented in Figure 8.4. For the field of object oriented programming (Google: “oriented programming”) the distribution is presented in Figure 8.5. For the field of computer architecture (Google: “computer architecture”) the distribution is presented in Figure 8.6. For the field of artificial intelligence (Google: “artificial intelligence”) the distribution is presented in Figure 8.7. For the field of performance evaluation (Google: “performance evaluation”) the distribution is presented in Figure 8.8. For the field of computer graphics (Google: “computer graphics”) the distribution is presented in Figure 8.9. For the field of multiprocessor systems (Google: “multiprocessor systems”) the distribution is presented in Figure 8.10.

The overall conclusion is, for the theory oriented research, methods U1 and U2 prevail; for the practice oriented research, methods H1, H2, T1, and T2 prevail.

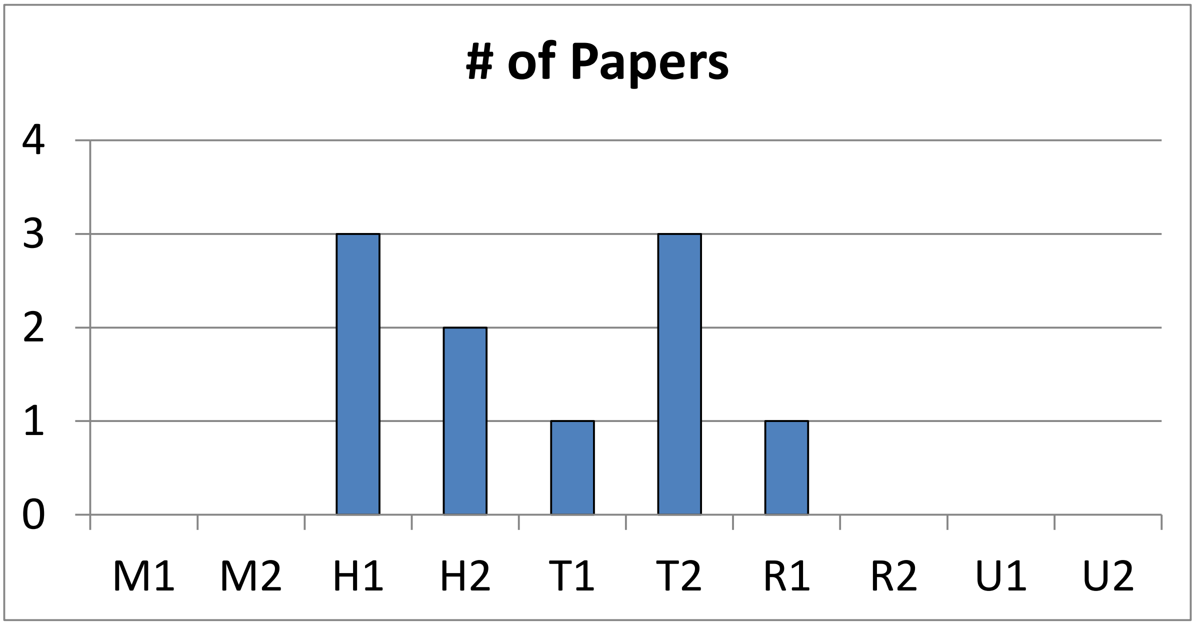


Figure 8.1. Distribution of innovation methods for "information systems"

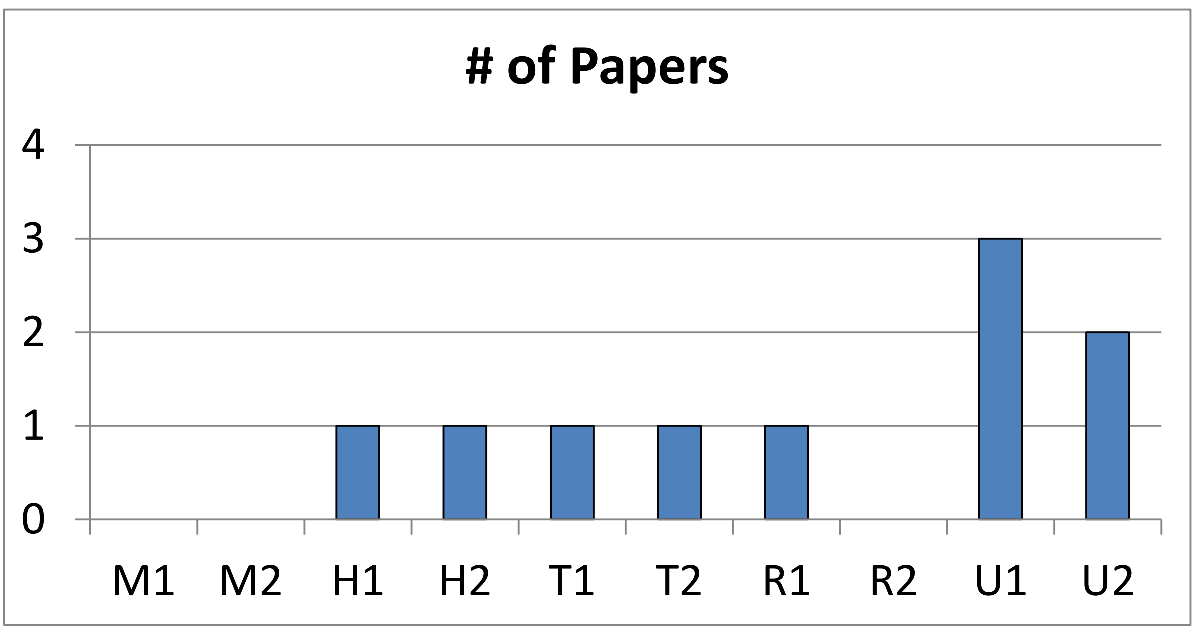


Figure 8.2. Distribution of innovation methods for "Optimizing Compilers"

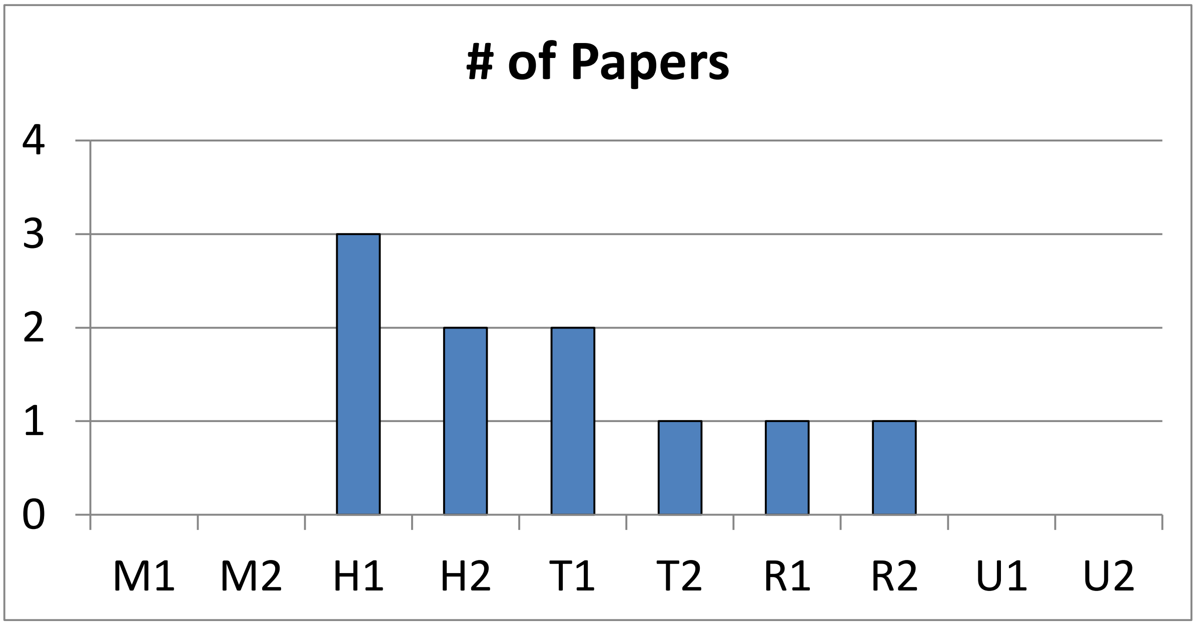


Figure 8.3. Distribution of innovation methods for "Database Technology"

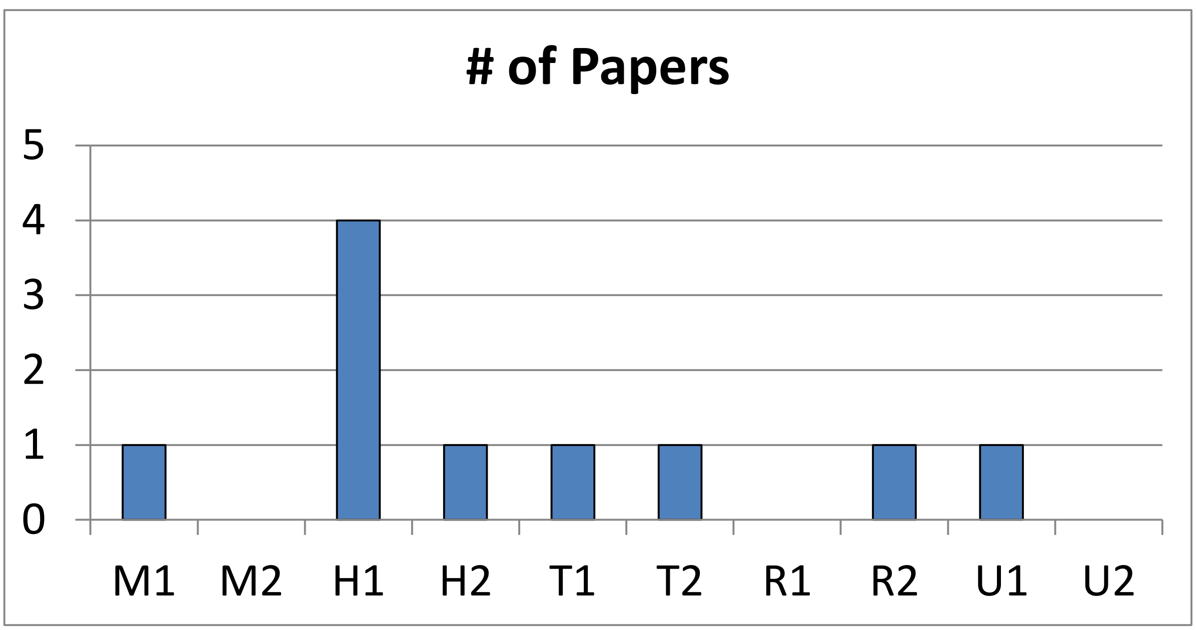


Figure 8.4. Distribution of innovation methods for "Interconnection Networks"

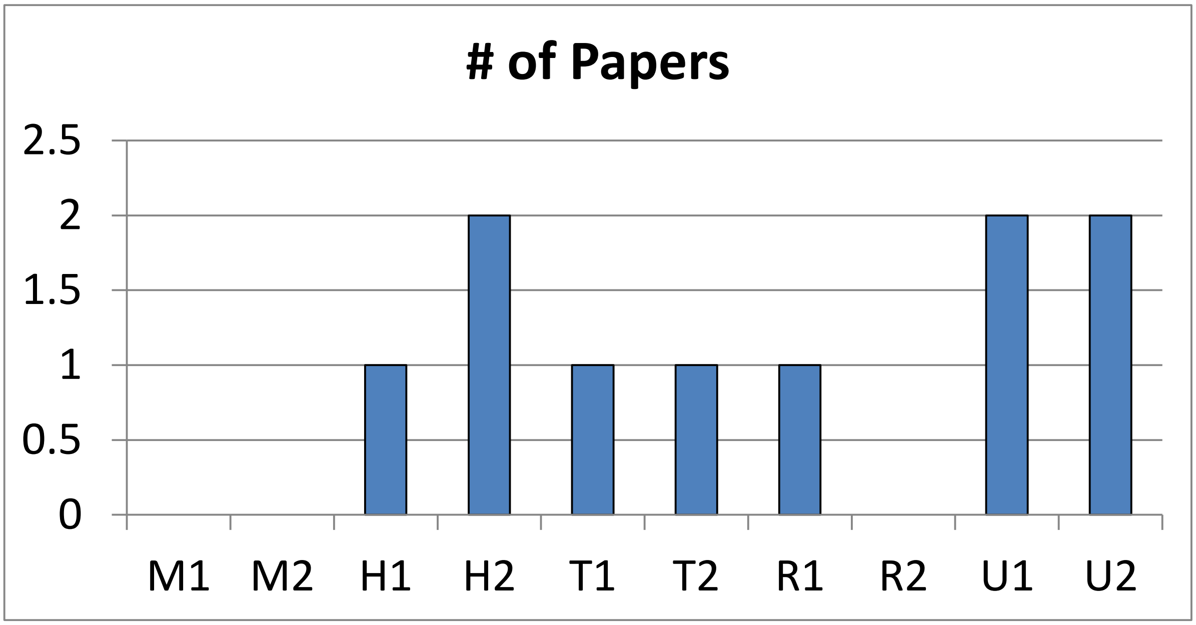


Figure 8.5. Distribution of innovation methods for "Object Oriented Programming"

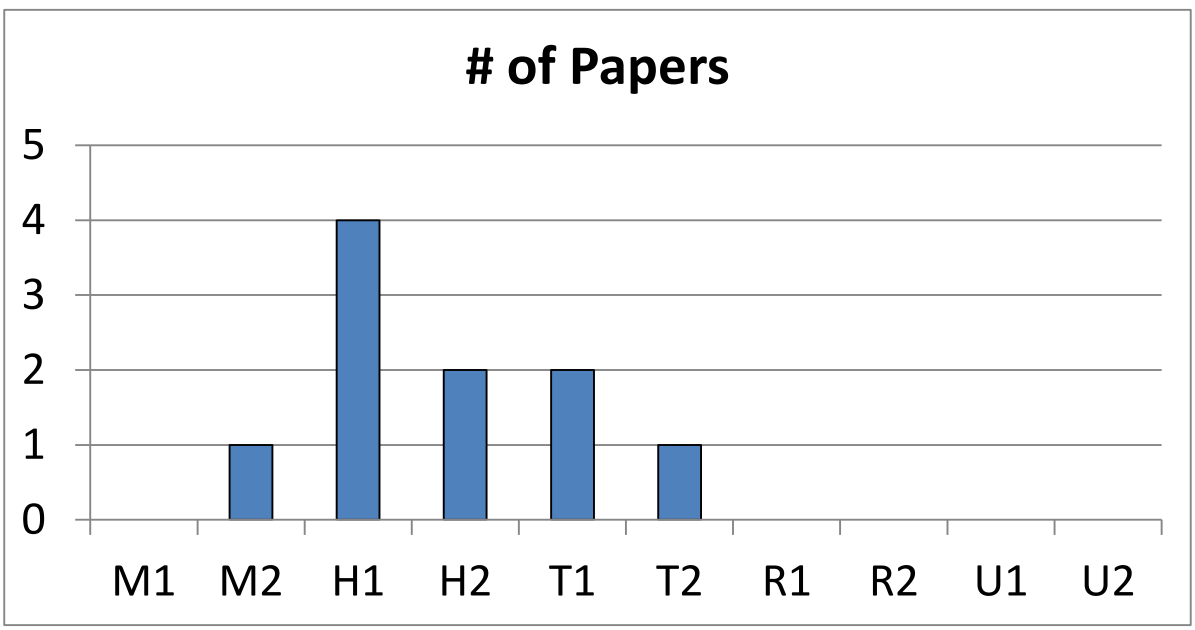


Figure 8.6. Distribution of innovation methods for "Computer Architecture"

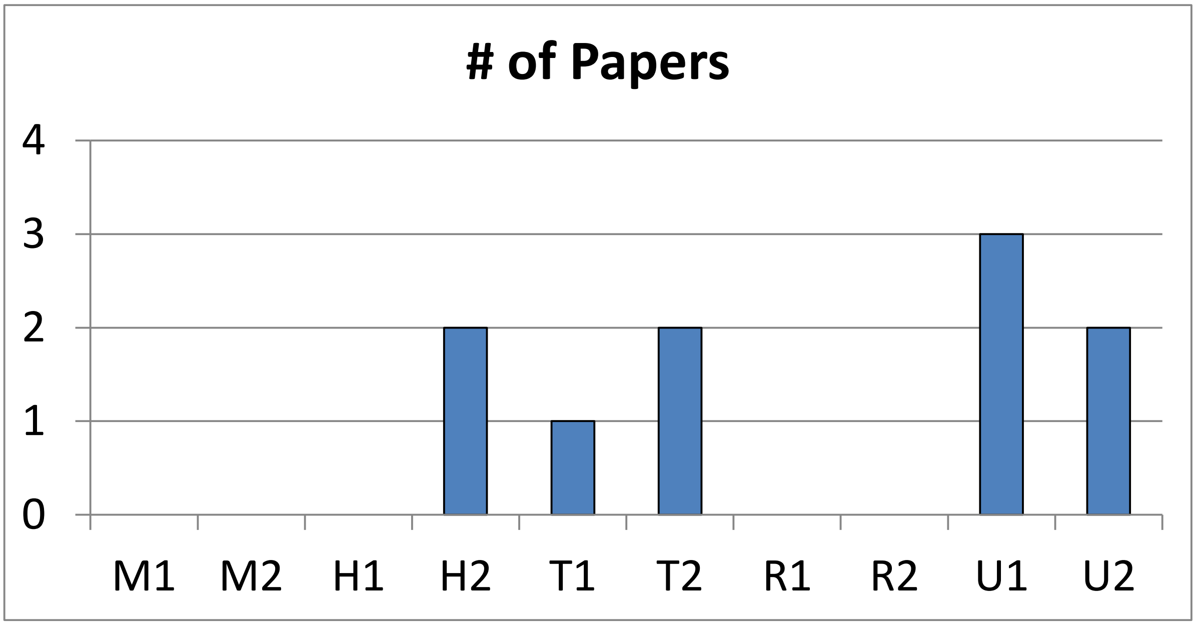


Figure 8.7. Distribution of innovation methods for “Artificial Intelligence”

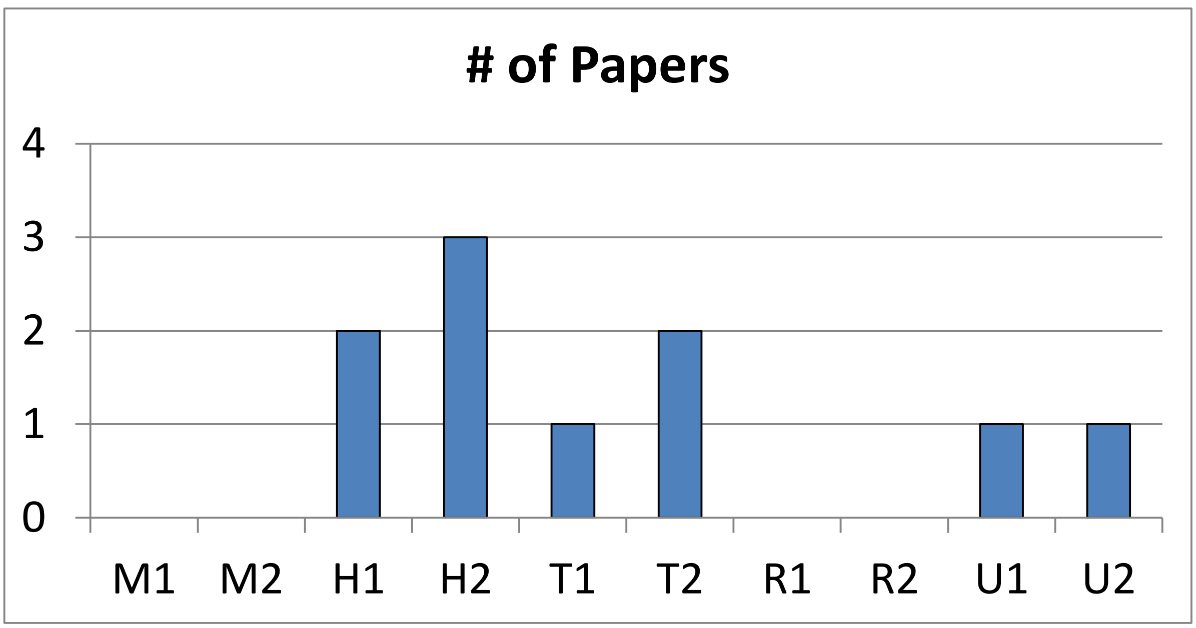


Figure 8.8. Distribution of innovation methods for “Performance Evaluation”

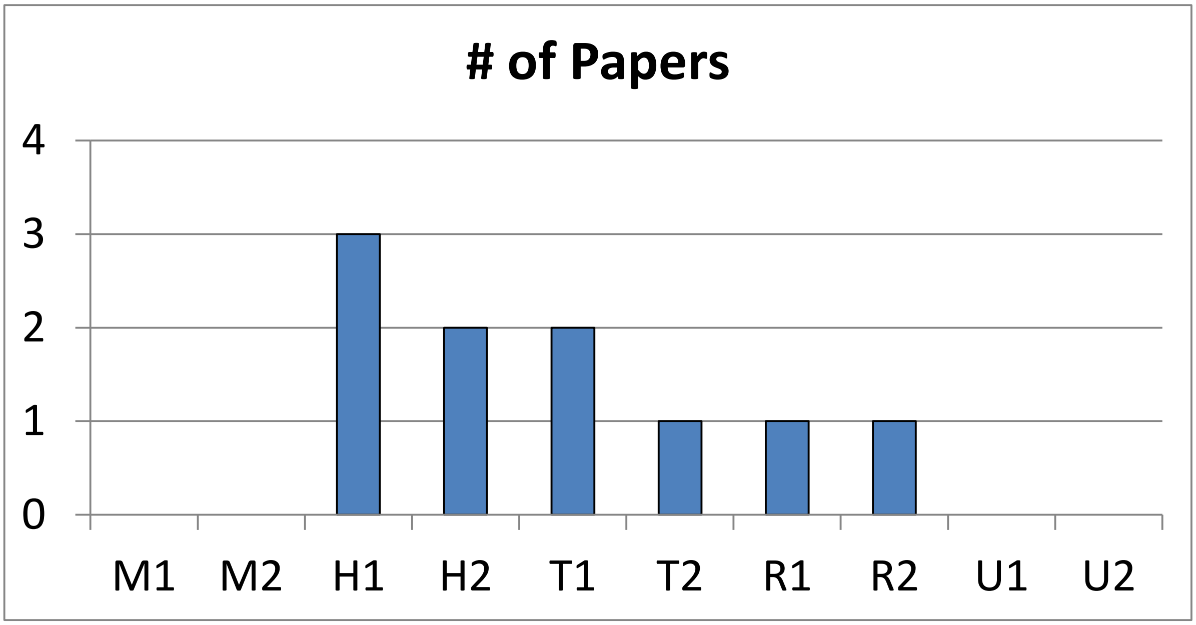


Figure 8.9. Distribution of innovation methods for "Computer Graphics"

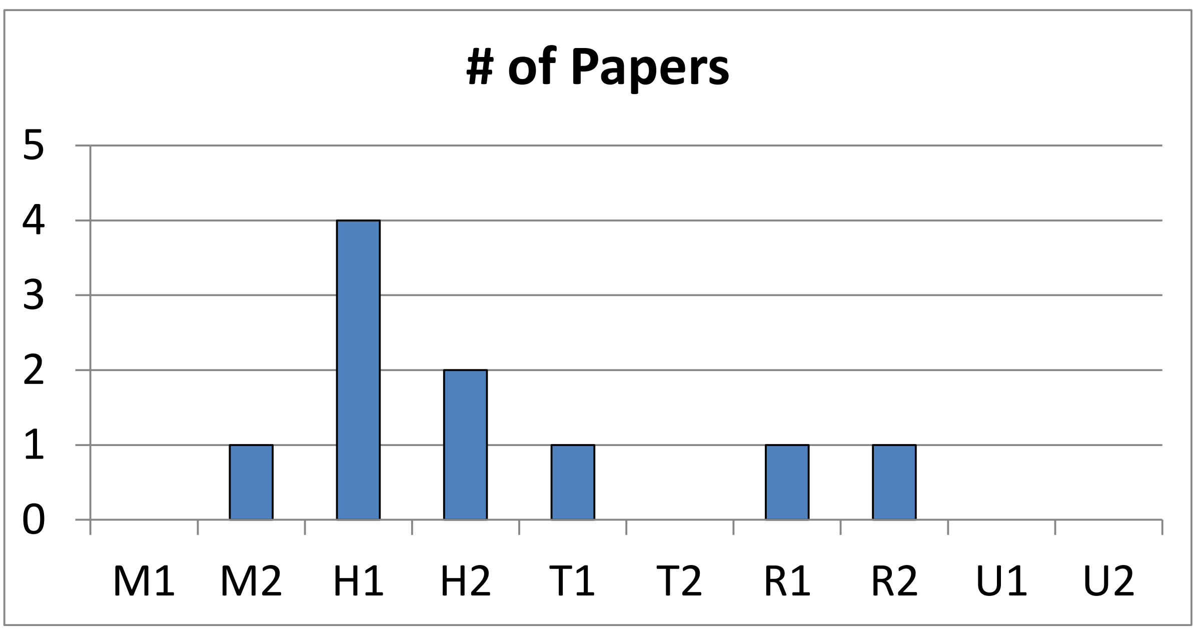


Figure 8.10. Distribution of innovation methods for "Multiprocessor Systems"

9. Examples from Authors of this Paper

This section presents the essence of past innovations of the authors of this paper and classifies them into the 10 idea generation methods introduced in this paper.

The PhD thesis of Vladimir Blagojevic [Blagojevic] introduces an innovation predominantly along the lines of the method U1.

The PhD thesis of Dragan Bojic [Bojic] introduces an innovation predominantly along the lines of the method R1. In the domain of reverse engineering, behavioral elements of the UML software model, a feature interaction problem in mapping features to code, is solved using a novel concept: lattice representation.

The PhD thesis of Miroslav Bojovic [Bojovic] introduces an innovation predominantly along the lines of the method H1.

The PhD thesis of Slavko Gajin [Gajin] introduces an innovation predominantly along the lines of the method H2.

The PhD thesis of Dragan Milicev [Milicev] introduces an innovation predominantly along the lines of the method U1.

The PhD thesis of Veljko Milutinovic [Milutinovic] introduces an innovation predominantly along the lines of the method M1.

The PhD thesis of Bosko Nikolic [Nikolic] introduces an innovation predominantly along the lines of the method R1.

The PhD thesis of Jelica Protic [Protic] introduces an innovation predominantly along the lines of the method T1.

The PhD thesis of Igor Tartalja [Tartalja] introduces an innovation predominantly along the lines of the method T2.

The PhD thesis of Milo Tomasevic [Tomasevic] introduces an innovation predominantly along the lines of the method H2.

10. Experiences with PhD Students of the Authors of this Research

This section presents the essence of the innovations of 10 different PhD students guided by 10 of the coauthors of this paper, which took an active part in this study. Each PhD student was asked to do a survey of a chosen field, and was asked to try to introduce improvements along the lines of all 10 methodologies presented in this paper. The most successful ideas represented the ground for the follow up research paper. The text to follow specifies which method was used in each particular piece of research.

The research effort of Drazen Draskovic in the domain of mutation algorithms for genetic search [Draskovic2012] gives an overview of existing methods and offers an idea predominantly along the lines of the method H1.

The research effort of Bojan Furlan in the domain of opinion mining for social networks [Furlan2011] gives an overview of existing methods and offers an idea predominantly along the lines of the method H1.

The research effort of Nemanja Kojic in the domain of data mining for wireless sensor networks [Kojic2012] gives an overview of existing methods and offers an idea predominantly along the lines of the method U1.

The research effort of Marko Misic in the domain of interconnection networks for multiprocessor systems [Misic2011] gives an overview of existing methods and offers an idea predominantly along the lines of the method R2.

The research effort of Milos Cvetanovic in the domain of system software for wireless sensor networks [Cvetanovic2008] gives an overview of existing methods and offers an idea predominantly along the lines of the method H1.

The research effort of Zaharije Radivojevic in the domain of application software for wireless sensor networks [Radivojevic2008] gives an overview of existing methods and offers an idea predominantly along the lines of the method H1.

The research effort of Zarko Stanisavljevic in the domain of computing infrastructure for distant education [Stanisavljevic2011] gives an overview of existing methods and offers an idea predominantly along the lines of the method R1.

The research effort of Zivojin Sustran in the domain of cache management for multiprocessor systems [Sustran2012] gives an overview of existing methods and offers an idea predominantly along the lines of the method T2.

The research effort of Djordje Djurdjevic in the domain of computer graphics for mission applications [Djurdjevic2011] gives an overview of existing methods and offers an idea predominantly along the lines of the method R1.

The research effort of Sasa Stojanovic in the domain of hybrid computing for supercomputer architecture [Stojanovic2012] gives an overview of existing methods and offers an idea predominantly along the lines of the method H1.

11. Conclusions

This paper introduces and explains 10 different methods that one can use to generate ideas for PHD research. It also analyses: (a) the most successful research efforts (Nobel Prizes and von Neumann Medals), (b) the most referenced papers in general computer science and engineering and the most referenced papers of the researchers with the highest h index in computer science and engineering, as well as (c) the contributions of the PhD theses of the authors of this paper and their PhD students. All the analyzed pieces of research are classified into the 10 presented methods.

This study is of benefit to PhD students who are eager to generate original ideas that could serve the basis of their PhD research. The presented methodology implies that the PhD student is first asked to create a survey of existing solutions to the problem attacked by his/her PhD research. The classification may include classes without examples, which opens doors for methodologies M1/M2. Algorithms/approaches inherent to various examples in different classes can be combined, which opens doors for methods H1/H2. Further on, with less or more modifications, one can port algorithms/approaches from one field to other fields, which opens doors for methods T1/T2. If conditions related to the understanding of the environment change, or our perception of the environment changes, doors get open for methods R1/R2. Finally, a bird's view or the worm's view of the surveyed examples may bring improvements along the lines of methods U1/U2.

Future work on this subject implies that the conclusions generated by the authors of this paper (as far as what research innovation belongs to what idea generation method) be verified from the authors of the original papers from the list of the most referenced ones. Also, as the experiences are gained in the work with PhD students, a follow up paper (maybe a decade later) could summarize new findings related to the advisory work with young talents using the idea generation methodologies advocated in this paper.

12. Classified References Used in the Educational Process

A course at the University of Belgrade teaches the methodology of this research to undergraduate and graduate students, and gives them 10 handouts (10 papers based on the 10 innovation approaches presented here). These 10 papers are listed bellow.

M1: Mendeleyevization/Inductor

[Milutinovic86a] *Milutinovic, V., Fortes, J., Jamieson, L.,*
A Multiprocessor Architecture for Real-Time Computation of a Class of DFT Algorithm,
IEEE Transactions on Acoustics, Speech, and signal Processing, Aol. ASSP-34, No. 5, October 1986, pp. 1301-1309.
(impact factor 1.463/1992).

M2: Mendeleyevization/Catalyst

[Milutinovic87c] *Milutinovic, V.,*
A Simulation Study of the Vertical-Migration Microprocessor Architecture,
IEEE Transactions on Software Engineering, Vol. SE-13, No. 12, December 1987, pp. 1265-1277.

H1: Hybridization/Symbiosis

[Milutinovic85] *Milutinovic, V.,*
A Microprocessor-Oriented Algorithm for Adaptive Equalization,
IEEE Transactions on Communications, Vol COM-33, No 6, June 1985, pp. 522-526.
(impact factor 1.512/2010).

H2: Hybridization/Synergy

[Milutinovic87b] *Milutinovic, V., Lopez-Benitez, N., Hwang, K.,*
A GaAs-Based Microprocessor Architecture for Real-Time Applications,
IEEE Transactions on Computer, VolC-36, No 6, June 1987, pp. 714-727.
(impact factor 1.822/2010).

T1: Transdisciplinarization/Modification

[Milutinovic86b] *Milutinovic, V.,*
GaAs Microprocessor Technology,
IEEE Computer, Vol 19, No. 10, October 1986 (Invited, Guest Editor's Introduction), pp. 10-15.
(impact factor 2.205/2010).

T2: Transdisciplinarization/Mutation

[Milutinovic87a] *Milutinovic, D., Milutinovic, V., Soucek, B.,*
The Honeycomb Architecture,
IEEE Computer, Vol. 20, No. 4, April 1987 (Open Channel), pp. 81-83.
(impact factor 2.205/2010).

R1: Remodeling/Granularization

[Milutinovic88] *Milutinovic, V.,*
A Comparison of Suboptimal Detection Algorithms
Applied to the Additive Mix of Orthogonal Sinusoidal Signals, IEEE Transactions on Communicatiions, Vol. COM-36, No. 5, May 1988, pp. 538-543.

R2: Remodeling /Reparametrization

[Milutinovic89] *Milutinovic, V., Bettinger, M., Helbig, W.,*
Multiplier/Shifter Design Trade-offs in a 32-bit Microprocessor,
IEEE Transactions on Computers, Vol. 38, No. 6, June 1989, pp. 847-880.
(impact factor 1.822/2010).

U1: Unorthodoxization/ViewFromAbove

[Milutinovic2000] *Milutinovic, V., Cvetkovic, D., Mirkovic, J.,*
"Genetic Search Based on Multiple Mutation Approaches,"
IEEE Computer, 2000. (impact factor 1.822/2010).

U2: Unorthodoxization/ViewFromInside

[Milutinovic2001] *Milutinovic, V., Ngom, P., Stojmenovic, I.,*
"STRIP --- A Strip Based Neural Network Growth Algorithm for Learning Multiple-Valued Functions,"
IEEE Transactions on Computers, 2001. (impact factor 1.822/2010).

Education Related References

[Milutinovic95] *Milutinovic, V., "The Best Method for Presentation of Research Results," IEEE TCCA, September1995.*

[Milutinovic96] *Milutinovic, V., 1996 "A Good Method for Presentation of Research Results, "IEEE TCCA, March 1996.*

[Milutinovic2008] *Milutinovic, V., Tomazic, S.,*
"How to Ruin the Career of a PhD Student,"
IPSI Transactions, July 2008.

[Milutinovic2012] *Milutinovic, V., Korolija,N.,*
A Short Course for PhD Students in Science and Engineering:
"How to Write Papers for JCR Journals," to be submitted, January 2012.

Methodology Related References

[Kline86]
http://books.google.com/books?hl=en&lr=&id=-nT3zZRenrUC&oi=fnd&pg=PA275&dq=methodologies+for+research+innovation+in+science+and+engineering&ots=ZQlJjm0WzF&sig=p1h6d0mjblCBcdBrdNt0CcN7m_I
[Faulkner94]
http://sth.sagepub.com/content/19/4/425.short
[Cummings2005]
http://sss.sagepub.com/content/35/5/703.short
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https://www.msu.edu/~libarkin/Publications_files/ResMeth-v50n4p449.pdf
[Linn87]
http://onlinelibrary.wiley.com/doi/10.1002/tea.3660240302/abstract
[Swan97]
http://onlinelibrary.wiley.com/doi/10.1111/1467-8551.0050/abstract
[Perkmann2007]
http://onlinelibrary.wiley.com/doi/10.1111/j.1468-2370.2007.00225.x/full
[Pavon2005]
http://www.igi-global.com/chapter/agent-oriented-methodologies/5061
[Iivari2007]
http://dl.acm.org/citation.cfm?id=2017331
[Wang2003]
http://en.cnki.com.cn/Article_en/CJFDTOTAL-JSJJ200312009.htm
[Stierand2011]
Stierand, M. & Dorfler, V., "Methods against Methods," Anabela Mesquita Technology for Creativity and Innovation: Tools, Techniques and Applications, IGI Global, Hershey, 2011, PA, 121-134.
[Dorfler2010]
Dorfler, V., "Fit for Innovation, Adam Jolly The Innovation Handbook: How to Profit from your Ideas," Intellectual Property and Market Knowledge, Kogan Page, London, 2010, 150-153.
[Dorfler2012]
Dorfler, V. & Ackermann, F., "Understanding Intuition: The Case for Two Forms of Intuition, Management Learning", 2012
[DorflerBaracskai2010]
Dorfler, V., Baracskai, Z., and Velencei, J., "Understanding Creativity," Transactions on Advanced Research, 2010, 6(2): 17-25.

Nobel Price References

Arrow [IPSI Transactions]
Transactions on Advanced Research
Arrow, K.:
"Interview - Creativity for Recovery from Crisis"
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Cooper [Edited by V. Milutinovic, at al]
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