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CNS-1446622 CPS: Breakthrough: Toward Revolutionary Algorithms for Cyber-Physical Systems Architecture Optimization

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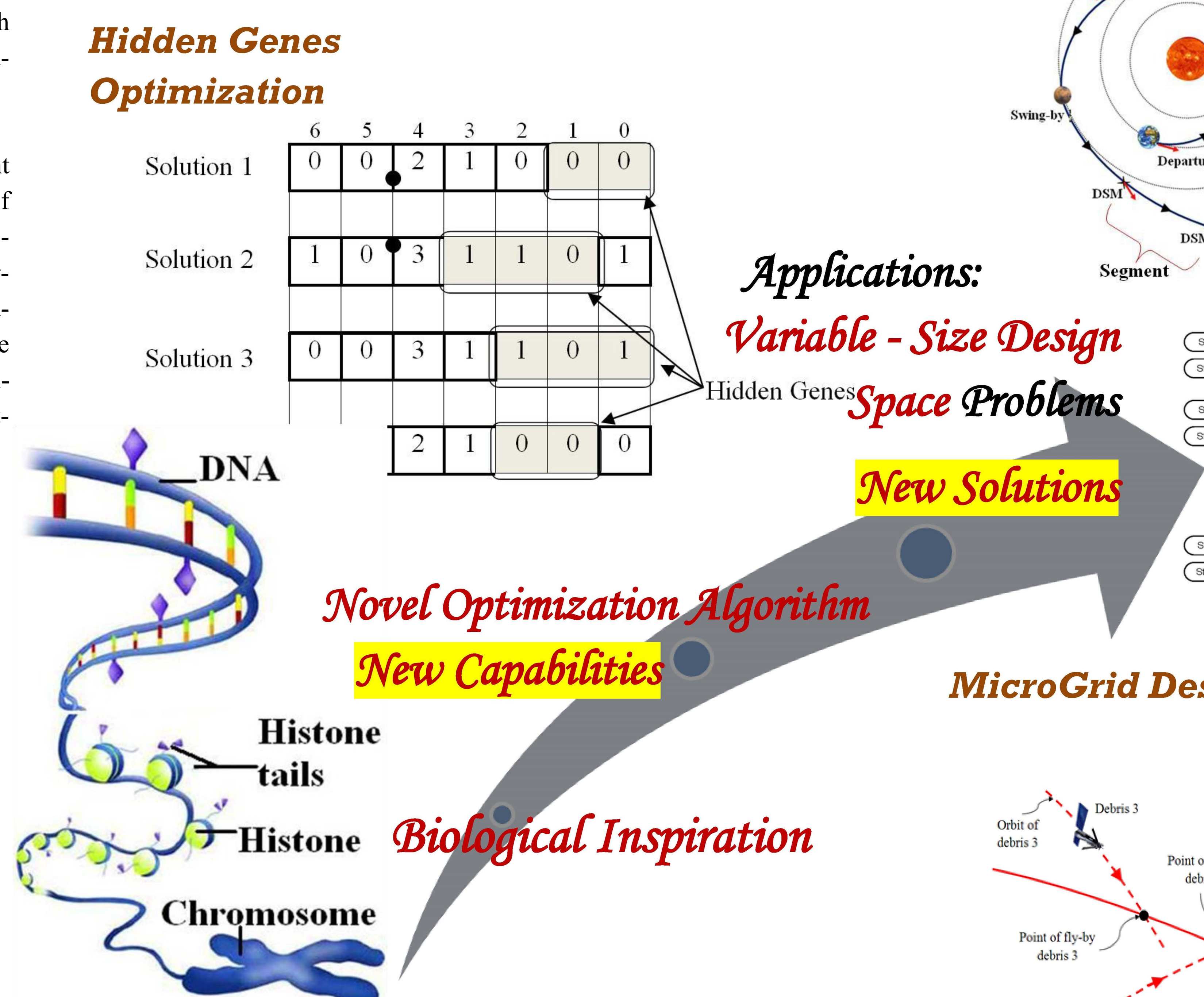
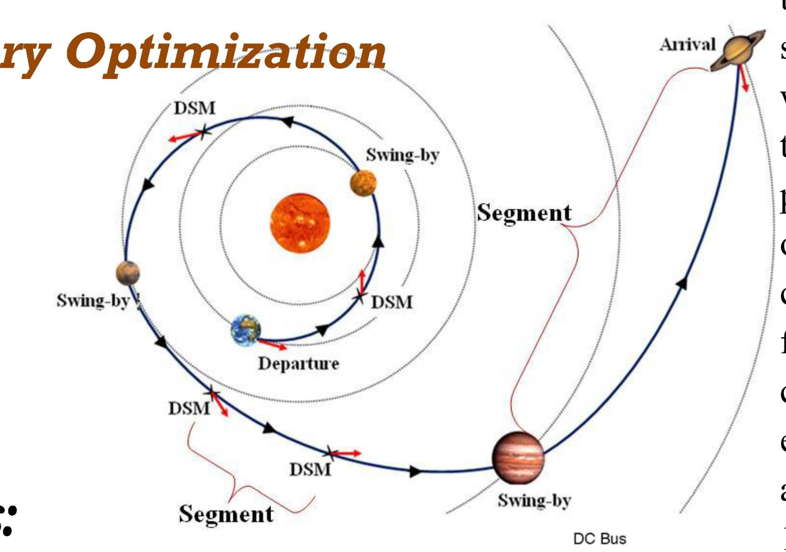
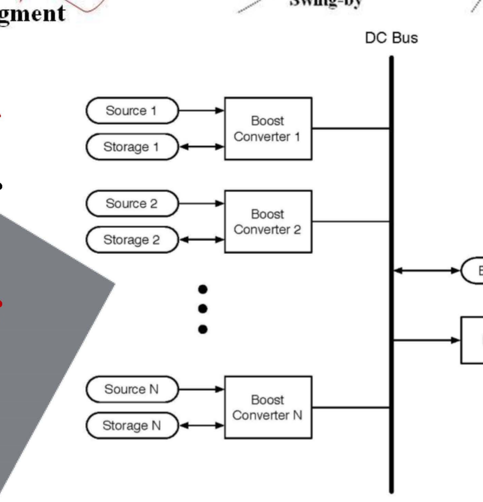
Abstract:

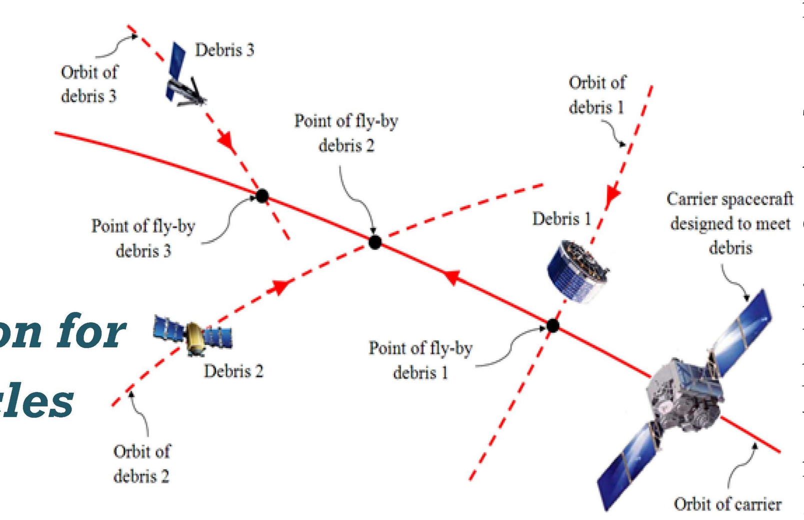
One of the challenges for the future cyber-physical systems is the exploration of large design spaces. Evolutionary algorithms (EAs), which embody a simplified computational model of the mutation and selection mechanisms of natural evolution, are known to be effective for design optimization. However, the traditional formulations are limited to choosing values for a predetermined set of parameters within a given fixed architecture. This project explores techniques, based on the idea of hidden genes, which enable EAs to select a variable number of components, thereby expanding the explored design space to include selection of a system's architecture. Hidden genetic optimization algorithms have a broad range of potential applications in cyber-physical systems, including automated construction systems, transportation systems, micro-grid systems, and space systems. The project integrates education with research by involving students ranging from high school through graduate school in activities commensurate with their skills, and promotes dissemination of the research results through open source distribution of algorithm implementation code and participation in the worldwide Global Trajectory Optimization Competition.

Instead of using a single layer of coding to represent the variables of the system in current EAs, this project investigates adding a second layer of coding to enable hiding some of the variables, as needed, during the search for the optimal system's architecture. This genetic hiding concept is found in nature and provides a natural way of handling system architectures covering a range of different sizes in the design space. In addition, the standard mutation and selection operations in EAs will be replaced by new operations that are intended to extract the full potential of the hidden gene model. Specific applications include space mission design, microgrid optimization, and traffic network signal coordinated planning.



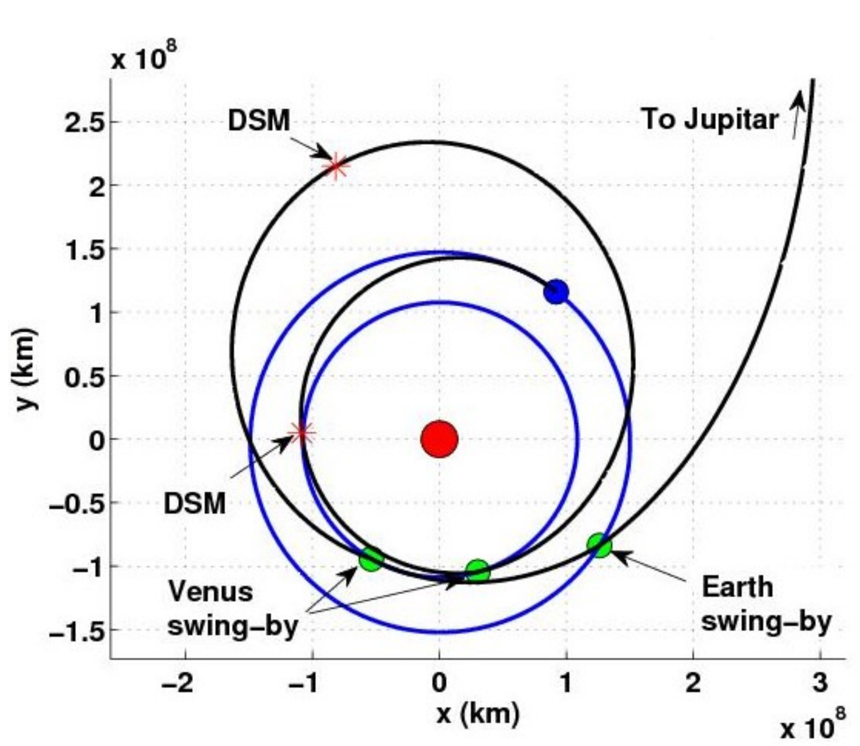


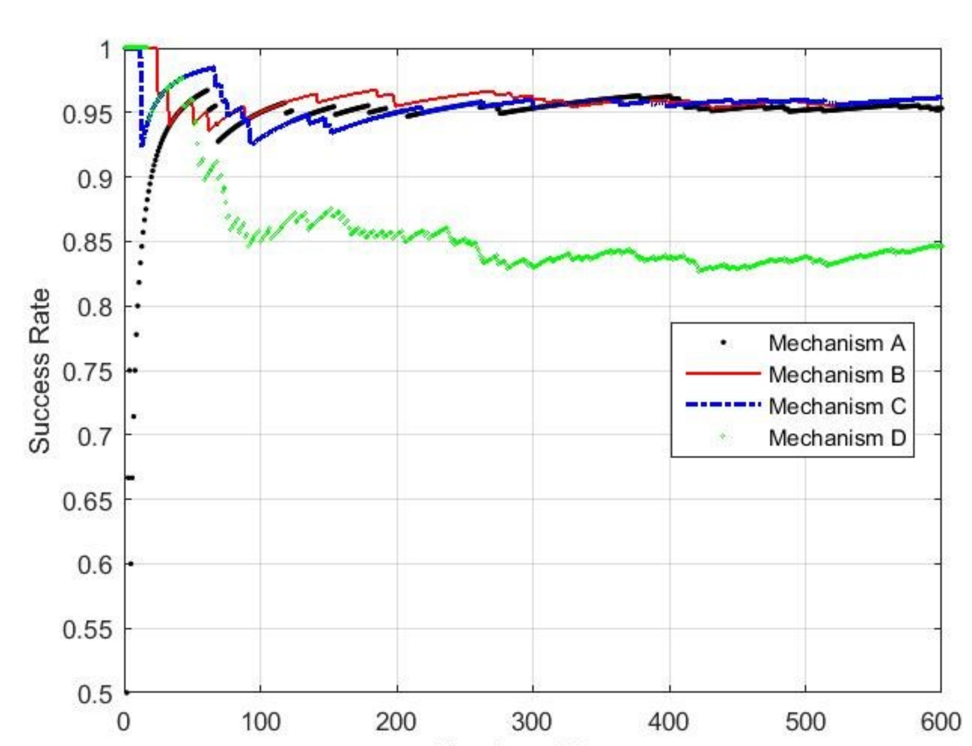




Application: Hidden Genes Genetic Algorithm for Multi-Gravity-Assist Trajectories Optimization

The problem of optimal design of a multi-gravity-assist space trajectory, with a free number of deep space maneuvers, poses a multimodal cost function. In the general form of the problem, the number of design variables is solution dependent. The hidden genes genetic algorithm (HGGA) method is developed to handle global optimization problems where the number of design variables vary from one solution to another. The HGGA method is applied to several interplanetary trajectory design problems. The HGGA method has the capability to determine the number of swing-bys, the planets to swing by, launch and arrival dates, and the number of deep space maneuvers, as well as their locations, magnitudes, and directions, in an optimal sense. The results presented in conference and journal papers show that solutions obtained using this tool match known solutions for complex case studies.





For more information, visit the Hidden Genes Genetic Algorithms website:

http://me.sites.mtu.edu/abdelkhalik/research/global-optimization/hidden-genes-genetic-algorithm/

Also watch our video on Hidden Genes Genetic Algorithms on youtube:

https://www.youtube.com/watch?v=d20_DGMW4Bg&feature=youtu.be

How Can The Hidden Genes Concept Optimize CPS Architectures?

The Hidden Genes Concept in Biology

In genetics, the deoxyribonucleic acid (DNA) is organized into long structures called chromosomes. Contained in the DNA are segments called genes. Each gene is an instruction for making a protein. These genes are written in a specific language. This language has only three-letter words, and the alphabet is only four letters. Hence, the total number of words is 64. The difference between any two persons is essentially because of the difference in the instructions written with these 64 words. Genes make proteins according to these words. Since, not all proteins are made in every cell, not every gene is read in every cell. For example, an eye cell doesn't need any breathing genes on. And so they are shut off in the eye. Seeing genes are also shut off in the lungs. Another layer of coding tells what genes a cell should read and what genes should be hidden from the cell [1]. A gene that is being hidden, will not be transcribed in the cell. There are several ways to hide genes from the cell. One way is to cover up the start of a gene by chemical groups that get stuck to the DNA. In another way, a cell makes a protein that marks the genes to be read; Figure 1 is an illustration for this concept. Some of the DNA in a cell is usually wrapped around nucleosomes but lots of DNA are not. The locations of the nucleosomes can control which genes get used in a cell and which are hidden [1].

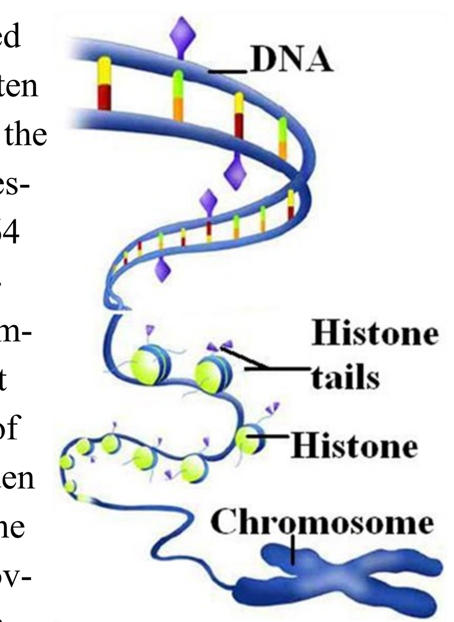


Figure 1: Chemical tags (purple diamonds) and the "tails" of histone proteins (purple triangles) mark DNA to determine which genes will be transcribed. (picture is modified from [1])

CPS Architecture Optimization using Hidden Genes

Standard genetic algorithms that are being used for optimization in numerous applications do not model hidden genes. As a result, all the solutions in the initial population have the same solution topology. In a microgrid system, standard genetic algorithms, when used for optimization, would assume the same number of storage devices in all the solutions in the population (this number is determined by the user,) and will search for the optimal values of the other system variables; e.g. the duty ratios at the converters. The standard genetic algorithms operations cannot change the solution topology in subsequent generations and hence this topology will remain fixed and the final solution will have the same topology.

This project investigates modeling the hidden genes in genetic algorithms (the concept can be applied to other evolutionary algorithms even though the discussion here focuses on genetic algorithms). A hidden gene in genetics does not get transcribed in the cell. Similarly, in the proposed the optimization algorithms, a hidden gene in a solution chromosome will not get transcribed in the fitness function, and hence will not affect the fitness of that solution. By introducing hidden genes in the chromosome that presents a solution, a population of solutions will have different solution topologies depending on which genes are being hidden in the individual solutions in that population. In microgrid systems, by modeling hidden genes we can have one solution that has for instance 100 storage devices and another solution with only 80 storage devices, by *hiding* the remaining 20 genes. Furthermore, by developing mechanisms that change (decide) which genes will be hidden in the offspring solutions, it is possible to develop topologies that do not exist in an initial population if they have potential of being more fit solutions. The microgrid example as it is presented here is a relatively simple example in the sense that different topologies is limited only to different number of storage devices. However, by considering all the various possibilities that we might have, in this example and in other applications, it is possible to see the potential impact of this proposed concept on developing totally innovative system configurations, when the proposed mechanisms add/remove/split system components in the configuration to optimize the given objective.