Intelligent Engineering

White Paper

Executive Overview

What is the dream of engineers? To spend time creating new design ideas, not on repetitive engineering. How can this dream be realized? In this paper, we describe NuEngineer™ a product and a methodology that aids in the realization of this dream. NuEngineer integrates applications, automates the reasoning between applications, and intelligently optimizes engineering designs across these applications.

Integrating and Optimizing across Engineer Applications

When engineers design parts and systems, they typically go back and forth between different software packages such as CAD, Analysis, and Costing tools. NuEngineer automates the process of going back and forth between different software packages and uses optimization and Artificial Intelligence (AI) techniques to automatically derive optimized designs across the different software packages. In this way it reduces repetitive engineering and enables engineers to spend their time on new engineering ideas.

Much of the cost associated with engineering is in transferring information back and forth between engineers and departments. NuEngineer automates this process as well as the reasoning being used during the transfer. NuEngineer not only works with reasoning between common engineering tasks but also reasons about (controls) the reasoning within the tasks. NuEngineer's reasoning about reasoning can be called meta-reasoning of the engineering process.

Optimizing Across Engineering Applications Such as CAD, Analysis and Costing Tools

Artificial Intelligence and Knowledge Based Engineering

There have been many advances in the fields of Artificial Intelligence and Knowledge Based Engineering in recent years. Some of these advances, such as chess programs, have made the front pages of newspapers; others have ushered in new products and/or created competitive advantages in the marketplace and are closely guarded as trade secrets.

Some of the most exciting advances are being made with self-adapting software systems that learn and/or evolve. Intelligent Evolution is a revolutionary new advance upon this theme. With intelligent evolution users have the added capability to direct evolution with human intuition and reasoning in order to dramatically improve the quality and performance of learning and evolution.

Recent advances in application integration allow the advances in Artificial Intelligence and Knowledge Based Engineering to be easily applied to Engineering Design. Advances in Application Integration include the development of numerous different integration mechanisms, standards, and API's such as TCP/IP sockets, DDE™, OLE™/COM™, DLL's as well as others. Some of these integration mechanisms even contain knowledge about themselves. (i.e. mechanisms to programmatically access definitions of the integration mechanism.)

The combination of these advances enables NuEngineer to usher in a new era of combined Human-Computer Intelligence where human intelligence is used for intuition and computer intelligence is used for computational power. Human engineers have intuition about how to guide search and reasoning as parts are designed, while computers have the computational power to accelerate search and reasoning within and across software applications.

In order to expound upon these ideas we discuss the following topics:

- ***NuEngineering™*** – A methodology for optimization across applications. This methodology includes three different engineering/software components: Engineering Design, Analysis, and Search/Optimization. Users intelligently create and search through hundreds of new designs and analyses in minutes, dramatically improving both the quality and speed of engineering.

- ***Engineering Application Integration™*** – A set of integration mechanisms contained within NuEngineer that dramatically reduce the development time required to capture knowledge by integrating with a broad base of legacy data, applications, tools, and platforms through PC and Intra/Internet interfaces. Meta-level integration is enabled through automated flow mechanisms, which pass information from application to application, visiting applications multiple times. The applications integrated, as well as their order and the flow between them can be dynamically varied through a visual interface. Applications can be integrated from design through manufacture.

- ***Human-Computer Intelligence™*** – The methodologies and mechanisms of NuEngineer was designed to enable the expression of human engineering design intuition within engineering software systems. In many situations, humans are able through intuition to reduce problem complexity from exponential to linear. NuEngineer was designed to capture that intuition.

- ***Intelligent Evolution™*** – Which generalizes many of the most exciting existing Intelligent Engineering Paradigms by embodying their underlying operational control elements. Using these elements Reasoning Engineers™ can create numerous different Combinations and Hybrids of Intelligent Engineering Paradigms. NuEngineer has many novel intelligent search capabilities including the abilities to: search in Multiple Directions; create Layers and Levels of Reasoning; and do Meta-Reasoning. The combination of these capabilities enables the expression of intuition within engineering software systems.

- ***Intelligent Engineering Paradigms*** enabled with NuEngineer include Heuristic Search, Genetic/Evolutionary Algorithms, Optimization, Case-based Reasoning, Neural Networks, Knowledge Based Engineering Meta-Rules, Meta-level Fuzzy Logic, as well as many other artificial intelligence technologies.

- ***NuEngineer's low cost*** is realized in three ways: first NuEngineer is itself low cost; second NuEngineer runs on a low cost platform; and third NuEngineer directly plugs into legacy applications thus dramatically reducing programmer time (and thus cost) required to capture knowledge.

NuEngineering

Imagine the engineer in a control tower commanding many computers and software systems in multiple directions of intelligent design. All systems report to the engineer with their results. The engineer, through his intuition, continues to command these systems in new directions of intelligent search and design. NuEngineer is the Engineers intelligent assistant enabling the Engineer to guide computational systems in multiple directions of search, optimization, and design.

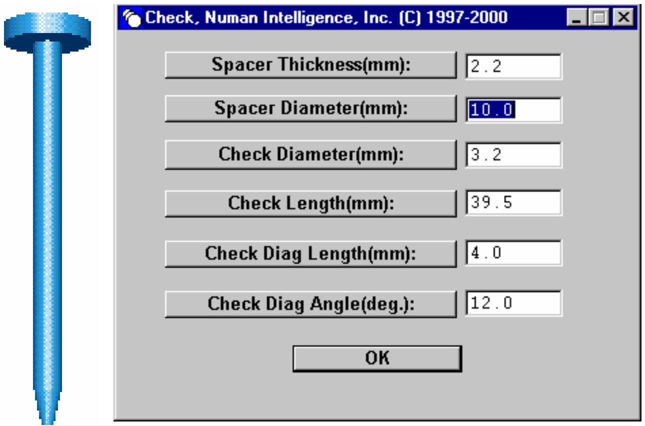
The simplest embodiment of the NuEngineer methodology has three components: Geometry, Analysis, and Search. The Search component is the unique component provided by NuEngineer, which allows users to dynamically create new intelligent searches. Using this methodology and

NuEngineer, users can create and search through hundreds of new designs and/or scenarios in minutes creating dramatic improvements for problem solving in both time and quality.

Design

Many modern CAD applications, either two or three dimensional can be controlled parametrically in some way. NuEngineer can control and optimize designs in such applications using these parametrically based interfaces. The most popular solids based CAD packages almost all have parametrically based API's and are thus perfect for the NuEngineer paradigm. Even older two dimensional CAD applications have API's that can be massaged to enable a parametric interface. A parametric interface can be as simple as the ability to input and output values from a spreadsheet cell an argument passed in and out of a program.

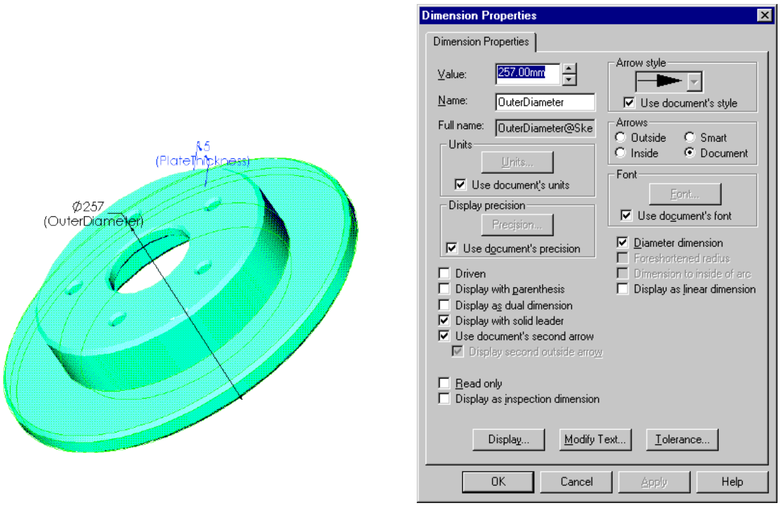
The most transparent example of a parametric interface to a CAD system is when a menu has been created to control important dimensions of a generic part. In such cases, the menu inputs include the dimensions and features of generic parts that vary from specific part to specific part. New CAD solid geometries can be created by setting values in menus, controlling the geometry parametrically. Setting the values in the menu at the right created the associated solid next to it. With such systems, engineers can experiment with the solid geometry via the menu. New solid geometries are generated in seconds. Such menu based systems are commonly built with intelligent CAD systems, or any ordinary CAD system with a program interface.


Check, Numan Intelligence, Inc. (C) 1997-2000

Spacer Thickness(mm):	2.2
Spacer Diameter(mm):	10.0
Check Diameter(mm):	3.2
Check Length(mm):	39.5
Check Diag Length(mm):	4.0
Check Diag Angle(deg.):	12.0

Geometry Input Menu And Resulting Solid Geometry Of A Fuel Injector Check

The most common and useful example of parametrically based interfaces is observable in off-the-shelf CAD applications. Most mid-range CAD packages provide OLE/COM interfaces while high-end packages typically provide Corba based parametric interfaces or C based API's. All of these interfaces are amenable to integration with NuEngineer. At right, you can see an example of the user's interface to parametric dimensions for a mid-range CAD package. These dimensions are also accessible via an OLE based interface. The user can cut and paste names from this user interface into NuEngineer in order to create a link between NuEngineer and this mid-rage CAD package.



Dimension Properties

Dimension Properties

Value: 257.00mm

Name: OuterDiameter

Full name: OuterDiameter@Ske

Units

☑ Use document's units

Display precision

☑ Use document's precision

☐ Driven
☐ Display with parenthesis
☐ Display as dual dimension
☑ Display with solid leader
☑ Use document's second arrow
☑ Display second outside arrow

☐ Read only
☐ Display as inspection dimension

Arrow style

☑ Use document's style

Arrows

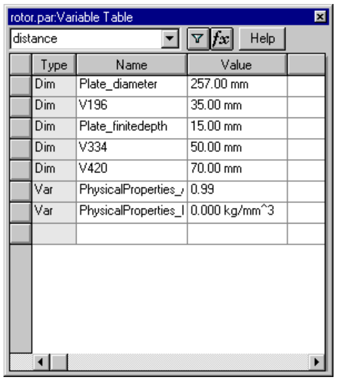
○ Outside ○ Smart
○ Inside ● Document

Font

☑ Use document's font

☑ Diameter dimension
☐ Foreshortened radius
☐ Dimension to inside of arc
☐ Display as linear dimension

Dimensions Automatically Created, Maintained, And Manipulated By A CAD System

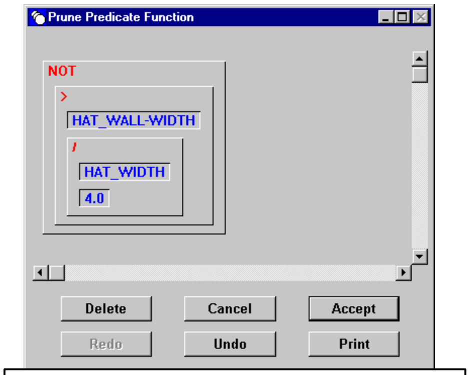


Type	Name	Value
Dim	Plate_diameter	257.00 mm
Dim	V196	35.00 mm
Dim	Plate_finitedepth	15.00 mm
Dim	V334	50.00 mm
Dim	V420	70.00 mm
Var	PhysicalProperties_/	0.99
Var	PhysicalProperties_I	0.000 kg/mm^3

Parameter Table Automatically Created By A CAD Package

Some CAD packages automatically create tables (seen at left) where the parametric dimensions can be accessed and modified. This almost mirrors the menu based interface discussed above. As with the above cases NuEngineer can access and control the dimensions contained in these tables. NuEngineer can also access physical/mass properties through the CAD packages interfaces.

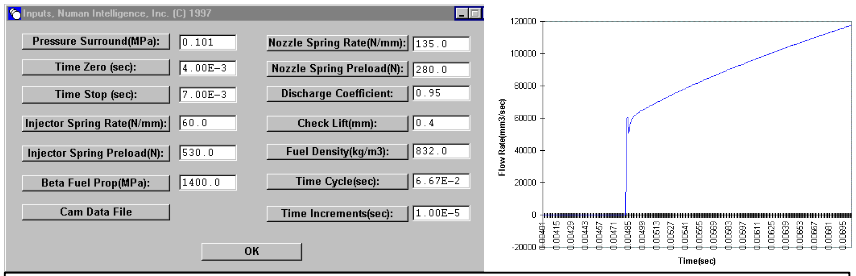
Another important attribute of CAD based systems, especially intelligent CAD systems, is the ability to create relationships and constraints. NuEngineer can leverage the relationships and constraints contained within CAD packages. In addition NuEngineer allows the creation of additional relationships and constraints with a visual interface (part of which is seen at right). This can be very important because some constraints and relationships may not be representable within specific applications. In some cases, the relationships and constraints are based on information coming from many applications not just one. Constraints and relationships can be created via visual functions on any information obtainable from the applications including symbolic information.



Pruning By Parameter Relationship

Analysis

Many analysis packages have API's and interfaces that can be used in the same way that CAD package interfaces are used. Like CAD systems there are many different kinds of analysis systems – commercial packages, GUI based programs, and non-GUI programs. For any engineering company, their analysis packages may be diversified across a broad base of different platforms. We first discuss a transparent example of an analysis package.

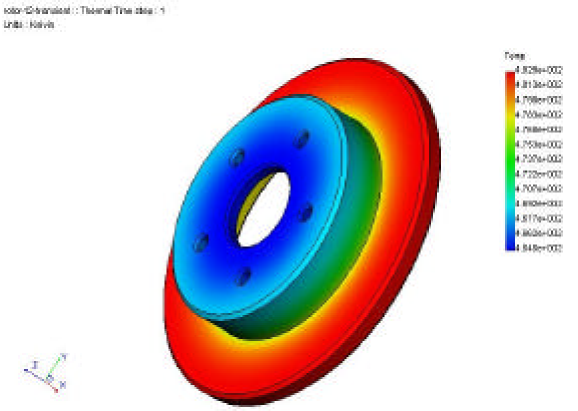


Pressure Surround(MPa):	0.101	Nozzle Spring Rate(N/mm):	135.0
Time Zero (sec):	4.00E-3	Nozzle Spring Preload(N):	280.0
Time Stop (sec):	7.00E-3	Discharge Coefficient:	0.95
Injector Spring Rate(N/mm):	60.0	Check Lift(mm):	0.4
Injector Spring Preload(N):	530.0	Fuel Density(kg/m3):	832.0
Beta Fuel Prop(MPa):	1400.0	Time Cycle(sec):	6.67E-2
		Time Increments(sec):	1.00E-5

Menu For Analysis Inputs And Associated Output

Like the first CAD example provided above a menu is associated with an application, in this case an analysis application. The menu is connected to a set of mathematical equations which provides analysis of the performance of the part being designed and output this performance analysis in graphical and/or other forms. The menu takes inputs that describe the larger system in which the part operates; material properties; test cycles; and more. Different inputs that affect the analysis of a fuel injector appear in the *inputs* menu above. Inputs can include data files and tables, dimensions of different solid parts in a larger system, variables describing the analysis cycle to be used, coefficients, as well as any other value. Outputs from the analysis can be masses, values, surface areas, graphs, and other types of information.

Recent advances in application integration makes the connection of off the shelf analysis applications inviting. NuEngineer utilizes DDE, OLE, socket, as well as other emerging interface standards. A number of FEA, CFD, motion tools have these types of interfaces. A base geometry for the part is first created in the CAD tool. An analysis predicting the performance of the part is then created in the analysis package.



FEA Analysis With API

NuEngineer is then connected to the Analysis and CAD packages, exporting and importing information from both applications. NuEngineer does not need to transfer extensive geometric information; most analysis tools already contain such transfer mechanisms. NuEngineer only needs to invoke these transfer mechanisms through their interfaces. NuEngineer has mechanisms to check for validity and for directing modification, so that if an analysis is invalid for a specific geometry, that geometry can be modified in a specific direction to make it pass validity tests.

NuEngineer can be very useful even if analysis and optimizing tools are available inside of CAD packages. This is because NuEngineer provides intelligence well beyond the capabilities of many other optimizing packages. Through API's NuEngineer can reach inside of other packages to provide intelligent optimization.

Search

Traditionally users go back and forth between CAD and Analysis packages one iteration at a time. Quite often, the switching is not only between packages but also between several different users (engineer, designer, and analyst). This is typically very time consuming, even though the parts being designed may be minor variations on previously designed parts for other product platforms. The coordination between different users and applications is a major bottleneck in the development process.

NuEngineer enables you to automatically search through hundreds of new designs across numerous different engineering applications and platforms (Unix, PC) in minutes creating dramatic improvements in both design time and design quality.

Optimization and intelligent search criteria are entered using NuEngineer. NuEngineer provides users the capability of intelligently selecting from the infinite number of possible new designs for those hundreds that are potential optimal designs and which geometric design and analysis should be done on. All of the inputs and outputs given in the Geometry and Analysis applications can be used as part of the criteria in the search. Different combinations of inputs and outputs can be dynamically chosen to intelligently guide search. NuEngineer starts to iterate. On each iteration, information is passed into and out of the CAD and Analysis packages wherein new geometries are created and tested for analytical performance. The results returned from these packages

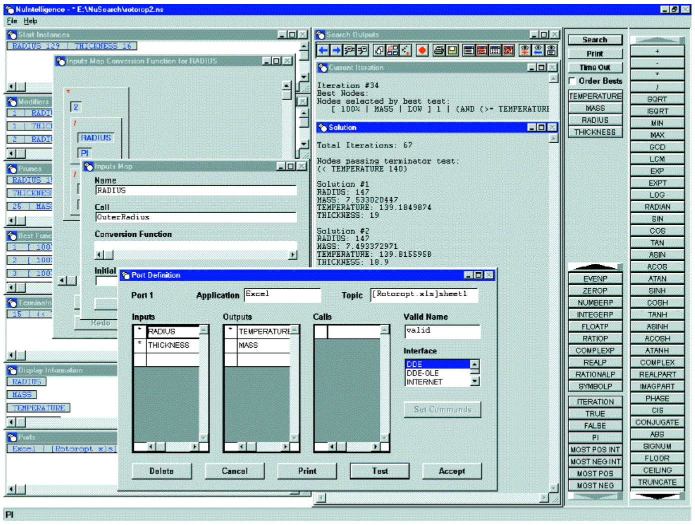
Search criteria are created dynamically by users and can be varied from search to search.

then guide future iterations by indicating which new geometries may be most promising for analytical performance. Geometries are searched for that satisfy analysis, geometric, mass and other criteria supplied by users.

NuEngineer can also be used to help tune analysis equations and packages with real world performance tests and data. This is because any input or output parameter can be monitored and intelligently modified including analysis. For example: the Discharge Coefficient in the Inputs menu appearing in the above Analysis section might be a value that is gained by expertise. You can use NuEngineer to vary the Discharge Coefficient and iterate through numerous different analyses, parts and data from real world tests to find the best Discharge Coefficient; thereby modifying the analysis equations to better model the real world.

Search Definition

NuEngineer incorporates a menu based visual language for describing intelligent search. Each specific part created and analyzed is considered an *instance* of a generic part. Search is done over hundreds of instances. The menu based visual language is used to specify how to create and choose instances to search through. The four most important components of an intelligent search are Start Instances, Modifiers, Prunes, and Best Functions.



```
Iteration #34
Best Nodes:
Nodes selected by best test:
   [ 100% | MASS | LOW ] 1 | (AND (>= TEMPERATURE

Total Iterations: 67

Nodes passing terminator test:
(< TEMPERATURE 140)

Solution #1
RADIUS: 147
MASS: 7.533020447
TEMPERATURE: 139.1849874
THICKNESS: 19

Solution #2
RADIUS: 147
MASS: 7.493372971
TEMPERATURE: 139.8155958
THICKNESS: 18.9
```

Name: RADIUS
Call: OuterRadius
Conversion Function
Initial

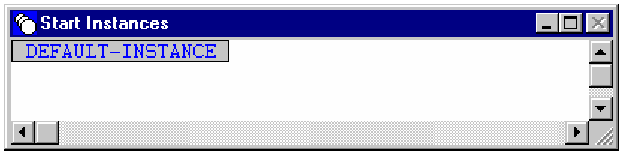
Port 1 Application: Excel Topic: [Rotoropt.xls]sheet1

Inputs: RADIUS, THICKNESS
Outputs: TEMPERATURE, MASS
Calls
Valid Name: valid
Interface: DDE, DDE-OLE, INTERNET

NuEngineer

Start Instance

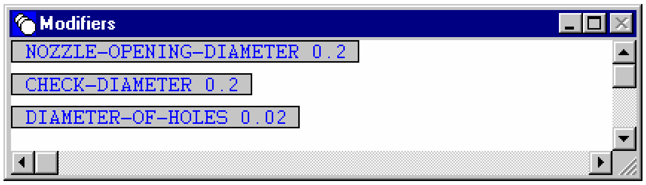
You can specify which instances with which to start. Any number of instances can be given at the start. In the menu displayed below there is only one start instance. It is the default instance and is composed of the solids and analyses existing in the CAD analysis and other applications that are interfaced with NuEngineer. Indicating which parameters differ from the default together with their parametric values can create alternatives to the default.



DEFAULT-INSTANCE

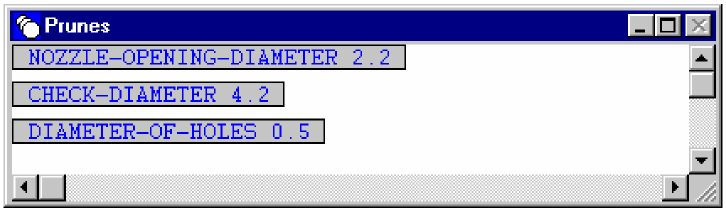
Modifiers

Users also specify how to start modifying the initial instances to come up with new instances in the search. In the example displayed at right, three parametric inputs are varied. The parameter names are given as well as how much to modify each input from its current value. For example, the Nozzle Opening Diameter input is varied by 0.2 mm on each iteration. Modification is done like the growth of a tree. In the given example the initial instance is modified in three different ways (Nozzle Opening Diameter, Check Diameter, and Diameter of Holes). Three new instances are created one for each of the different modifications. Each of these new instances will in turn be modified in three different ways creating nine new instances, etc. This example is one of the simplest methods for defining intelligent modification provided in NuEngineer.



NOZZLE-OPENING-DIAMETER 0.2
CHECK-DIAMETER 0.2
DIAMETER-OF-HOLES 0.02

Prunes



NOZZLE-OPENING-DIAMETER 2.2

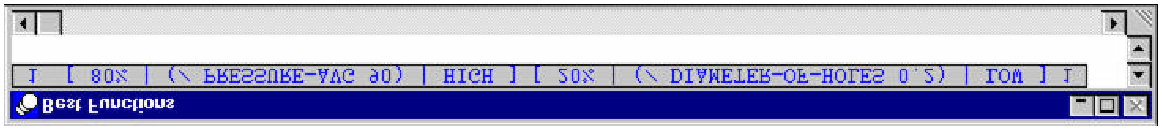
CHECK-DIAMETER 4.2

DIAMETER-OF-HOLES 0.5

If all instances were modified the number of instance would grow exponentially and any computational system would quickly be overwhelmed. One method for controlling the search is to provide Prunes that prune off branches of the tree. Prunes indicate when to stop searching down branches of the tree. In the Prunes box above any instance with a Nozzle-Opening-Diameter greater than 2.2 is removed from the search, as is any instance with a Check-Diameter greater that 4.2 or a Diameter-Of-Holes greater than 0.5. As with modifiers, we are only showing the simplest usage of the NuEngineer's pruning mechanism.

Best Functions

Another method of controlling search is Best Functions which select/limit the instances which are to be modified. The best function gives users the power to dynamically indicate what makes a specific instance of a part desirable. One Best Function is shown in the figure below. This function indicates that only the single instance with the best (high) Pressure-Avg and best (low) Diameter-Of-Holes should be chosen to be modified. The notation in the figure is a condensed form of the best function. This information is actually entered through several menus and visual functions. Visual functions are entered strictly through buttons and clicking and dragging and are described in more detail below.



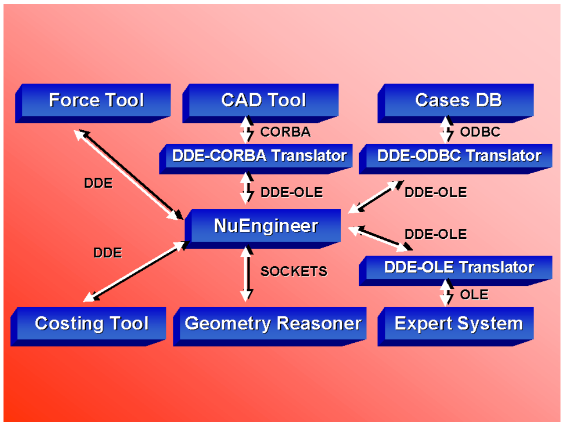
1 [80% | (\ PRESSURE-AVG 90) | HIGH] [20% | (\ DIAMETER-OF-HOLES 0.2) | LOW] 1

NuEngineer is unique because users have the full power to control search dynamically by choosing which inputs to modify, how to prune, which instances to grow first, as well as the ability to direct, relate and layer modifiers and bests.

Engineering Application Integration

The Engineering process is not solely undertaken within one application. NuEngineer provides the ability to not only integrate diverse engineering applications but to represent and automate the reasoning that takes place between applications. Integration can be across the entire manufacturing process. From design through testing, analysis, prototyping, systems design, casting/molding, machining, costing, bill of materials, assembly, scheduling, and delivery.

NuEngineer uses translators and adapters, as well as standard formats and other Application Integration tools. Numerous different forces are causing the emergence of interconnection standards and capabilities across a broad spectrum of engineering tools. This means that almost any set of applications (either currently, or in the near term) can be integrated with NuEngineer. To the right, we see NuEngineer integrating numerous applications together into a **distributed object** using numerous different integration techniques. All population



Integration Methods – Built-in Or Setup Only Once instances in NuEngineer are distributed objects. Information for each instance (object) being spread out across a number of applications.

The integration example above demonstrates: (1) the CAD tool does geometry; (2) the Geometric Reasoner has rules about stamping processes based on geometric features as inputs; (3) the Force Tool does Finite Element Analysis (FEA) on stamping of specific sheets of metal; (4) the Costing Tool does pricing of parts and materials; (5) the Cases DataBase contains past examples of parts that have been stamped as well as vehicles that the stamped parts were for; and (6) the Expert System contains diverse rules (e.g. about problems that may occur and go or no-go decisions about stamping processes) based upon diverse sets of information coming from different applications. NuEngineer routes information back and forth between the applications and intelligently optimizes for the lowest cost acceptable part and process.

Identification or construction of integration mechanisms is done only once at project startup. NuEngineer provides a powerful set of visual tools to dynamically specify or modify specific order of integration or specific pieces of information used to flow between applications. Once the integration mechanisms have been identified or built, applications can be removed, added or ordered at will through an easily understood visual user interface.

Integration Mechanisms

There are myriads of integration tools available to the engineering and computer industries. Integration can be a simple as passing inputs and outputs back and forth to as complex as application windows and transformations of complex data structures coming from multiple sources across the internet. Fortunately, NuEngineer needs only the simplest form of integration – passing inputs and outputs back and forth. NuEngineer can take advantage of the more complex forms of integration by: (1) calls to other applications to perform actions; (2) usage of other applications to do transformations; (3) NuEngineer's own visual capabilities to do complex mathematical and symbolic transformations; and (4) NuEngineer's capacity to intelligently direct traversal of links during complex data structure transformations.

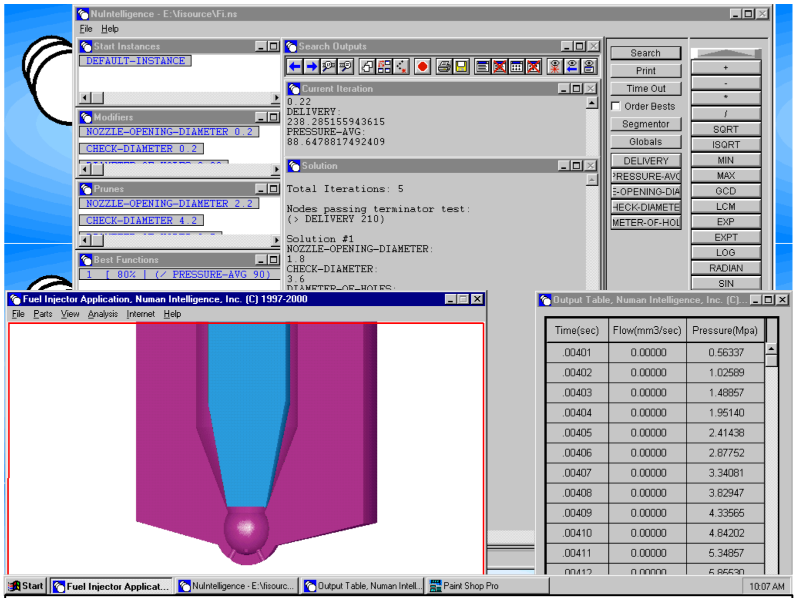
Integration mechanisms include sockets, DDE, COM, DCOM, JavaBeans, DLL's, XML, Enterprise Application Integration and applications specific API's. NuEngineer is native to the WIndows™ operating system. However, the applications it can integrate with, using sockets or translators, can exist on any platform. The professional version (available soon upon request) allows intelligent searches to be run natively on the user's choice of platforms.

Because of these application integration techniques, NuEngineer dramatically reduces the development time required to capture knowledge by integrating with a broad base of legacy data as opposed to forcing users to rewrite their legacy knowledge into a new application.

NuEngineer capabilities differ from that of Enterprise Application Integration (EAI) tools. First, EAI tools focus on the overall manufacturing enterprise not on the engineering or the manufacturing process that NuEngineer focuses on. EAI tools aid users in the transfer and organization of information between applications. Second, NuEngineer requires that the transfer of and organization of information be done up front and be in a cohesive fashion, such that a consistent distributed object is constructed. In this way, the integration becomes another layer of automation. NuEngineer then can optimize across this layer automatically chaining to repeatedly form application to application.

Composite Objects

Many integration mechanisms provide a centralized view through a specific application. Sometimes this means an Internet browser. NuEngineer's centralized view is through the default centralized view provided by the operating system. This includes the ability to have different communicating (interfaced) applications up in different windows, as seen at right. There are many tools available today which extend this capability across any network and platform. These additional tools allow users to bring up windows for applications that are running on numerous different platforms (Windows, Unix, Mainframe, and Macintosh) on one machine and operating system.



```
0.22
DELIVERY:
238.285155943615
PRESSURE-AVG:
88.6478817492409
```

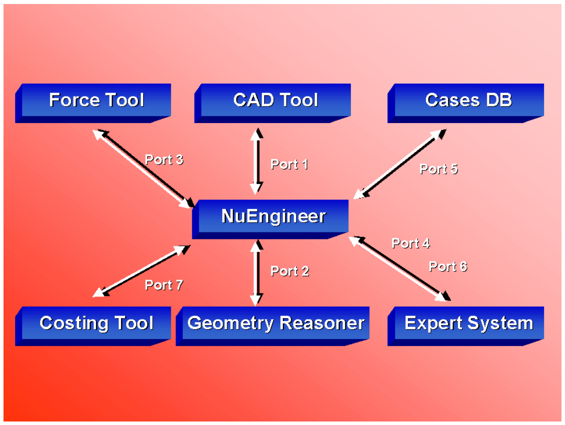
```
Total Iterations: 5

Nodes passing terminator test:
(> DELIVERY 210)

Solution #1
NOZZLE-OPENING-DIAMETER:
1.8
CHECK-DIAMETER:
3.6
DIAMETER-OF-HOLES:
```

Time(sec)	Flow(mm3/sec)	Pressure(Mpa)
.00401	0.00000	0.56337
.00402	0.00000	1.02589
.00403	0.00000	1.48857
.00404	0.00000	1.95140
.00405	0.00000	2.41438
.00406	0.00000	2.87752
.00407	0.00000	3.34081
.00408	0.00000	3.82947
.00409	0.00000	4.33565
.00410	0.00000	4.84202
.00411	0.00000	5.34857
.00412	0.00000	5.85530

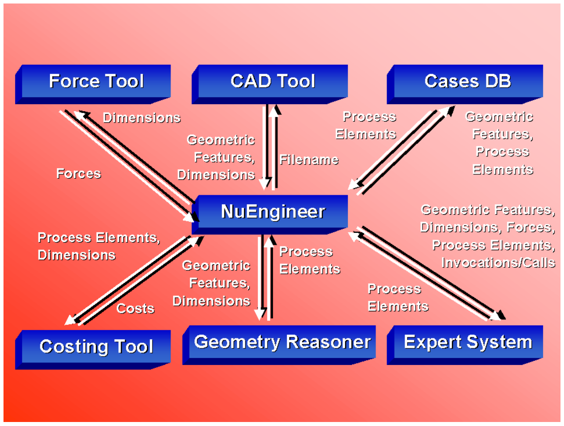
Multiple Applications Interacting, Up At Same Time. Design, Analysis And Intelligent Search

Reasoning Between Applications.

NuEngineer provides users the ability to represent reasoning between applications in a number of different ways. First, NuEngineer provides a number of common programming language constructs (+, - *, /, sin, cos, and, or, not, if, etc.). NuEngineer can pass numeric, symbolic and other data structures back and forth to other applications as well as send calls to other applications indicating that they need to act. Second, NuEngineer provides built-in data flow across the interface so that all of the applications integrated become a cohesive consistent distributed object. The interfaces can be easily and dynamically redefined using NuEngineer's built-in flow mechanisms. Third, NuEngineer has built-in optimization mechanisms that allow users to intelligently and dynamically define intelligent optimizations.



Port Flow - Dynamically Settable

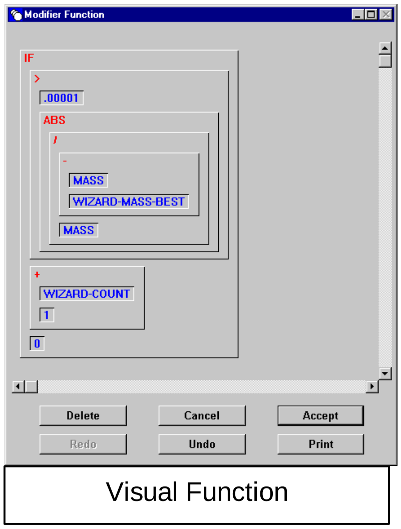

Force Tool
CAD Tool
Cases DB
Dimensions
Forces
Geometric Features, Dimensions
Filename
Process Elements
Geometric Features, Process Elements
NuEngineer
Process Elements, Dimensions
Geometric Features, Dimensions, Forces, Process Elements, Invocations/Calls
Geometric Features, Dimensions
Process Elements
Costs
Process Elements
Costing Tool
Geometry Reasoner
Expert System

Information Flow - Dynamically Settable

In the figure above, the definition of the order of visiting applications can be seen. In the figure below, left the definition of specific pieces and types of information passed back and forth between applications can be seen. Users can redefine the port order or specific pieces of information that flow at run time.

Visual Functions

NuEngineer has a novel visual language that simplifies the definition of mathematical and symbolic computation. Complex numeric and symbolic functions are all available through buttons and then through the clicking and dragging of boxes around each other. Part of this interface can be seen at right.

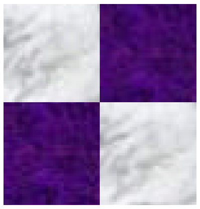


Visual Function

Human-Computer Intelligence

NuEngineer's embodies Human-Computer Intelligence. With NuEngineer human intelligence is used for intuition to intelligently guide the search, computer intelligence is used for computational power to carry out the search/optimization.

The best human chess players review hundreds of possibilities before making moves, while the best computer chess players review hundreds of trillions of possibilities and yet are only approximately equivalent in skill to the best human players. NuEngineer's focus is to enable the encoding of human intuition for searching through possibilities and then multiply it with the computational power of computers. NuEngineer is thus able to gain greater orders of magnitude in problem solving. More traditional Artificial Intelligence and other computational techniques, even in simple games, such as chess, need a computational power advantage of at least nine orders of magnitude in order to have problem solving capabilities equivalent to humans.



NuEngineer enables the reduction of problem complexity from exponential to linear to deal with combinatorial explosion via the encoding of Human Intuition

Optimization tools go relatively blindly through thousands and millions of iterations, too much for CAD, FEA, and other engineering tools. These engineering tools take too much time to tolerate this many iterations.

One of the examples (Npuzzle) provided with NuEngineer, demonstrates reductions in problem complexity from 100,000 to 10^{40} times. Users can dynamically define appropriate search depth depending upon the applications being integrated. If CAD or time expensive FEA applications are being integrated, users can define a small search tree depth so that search does not take too long. If spreadsheets and other relatively quick applications are indicated, users can define deeper searches. The term “Deeper” means a larger number of instances are visited/created. Numan Intelligence, Inc. consulting services can aid users in the creation of optimization wizards that can be created for specific engineering problems and applications.

Intelligent Evolution

NuEngineer is based on a new general theory of intelligent search/optimization. NuEngineer provides a structural view of Artificial Intelligence and Optimization. NuEngineer contains a superset of the operational control components underlying Heuristic Search, Genetic/Evolutionary Algorithms, and Optimization. (Here operational means what happens computational operation by operation. Control is defined as what mechanisms are used to order the operations.) Through minor extensions, many other Intelligent Engineering Paradigms including Neural Networks, and Case-based Reasoning can be represented. The mechanisms in NuEngineer that enable the representation of operational control components is patent pending.

NuEngineer can be described as ***Dynamic Directed Distributed Object Evolution*** (*DDDOE*). As the name suggests the items that *evolve* are *objects*. The evolution is *directed* in that evolution is not random, users explicitly create rules to direct the evolution of objects. The evolution is *dynamic* because users can redirect search interactively. The objects can be *distributed* across any number of legacy or new applications.

Two of the most important capabilities provided by NuEngineer manipulation of operational control components are the capabilities to *direct* and *layer* evolution which create exponential reductions in the populations that need to be investigated. Other capabilities created include the ability to intelligently combine and hybridize different Intelligent Engineering Paradigms.

Directed

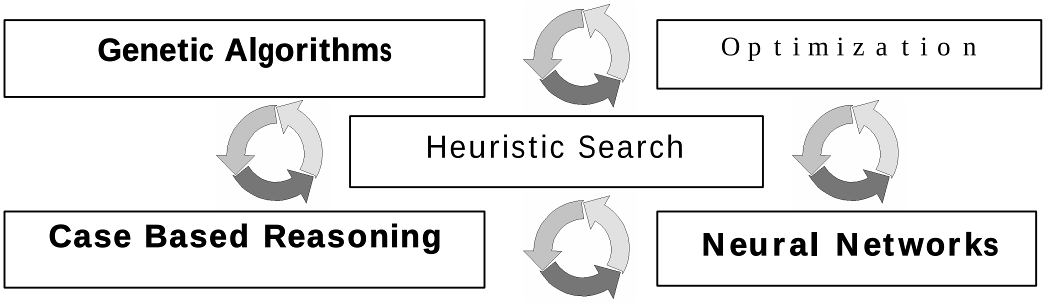
NuEngineer provides the ability to direct search in many different directions and combinations of directions through the use of multiple complex best functions, modifiers, and prunes. The problem space can be used to guide the search via intelligent rules that observe the search space and then direct the search.

Layer/Level

There are numerous mechanisms available in NuEngineer to level and layer search spaces. This includes: levels of best functions; modification based upon best levels; and segmenting of search space including removal of closed elements. Levels can also be learned using NuEngineer.

Combinations and Hybridizations

NuEngineer makes it possible to combine the best components of many different AI techniques to create hybridizations most applicable to specific problems.



Combining and Hybridizing
many diverse Intelligent Engineering Paradigms.

With NuEngineer, the user can create combinations and/or hybrids of Neural Networks, Genetic Algorithms, Optimization, Case-Based Reasoning and Heuristic Search. This includes the ability to hybridize between, sub-components of these techniques.

Meta-Reasoning

NuEngineer is a tool for expressing search and optimization. All of the operational control components of search and optimization are made available to users to create and manipulate. Thus, NuEngineer is a meta-search tool. Meta knowledge (knowledge of the search as it is progressing) can also be use to control the search. NuEngineer allows users to create intelligent rules for selection of the most effective search technique as search is happening.

Information on the search can also be passed back into the problem space representation to aid in the creation of better heuristics in that problem space. The problem space is where main heuristics exist. The problem space can be considered the external applications that NuEngineer is interfaced with (e.g. CAD, FEA applications). By separating the problem space from the search space, NuEngineer users can more clearly reason about search. By passing search knowledge into the problem space, intelligent heuristics can be learned for describing what is good in the problem space.

The most common form of Intelligent Engineering is that of Knowledge-Based Engineering. NuEngineer goes beyond this paradigm to one of Reasoning Engineering. With NuEngineer Reasoning Engineers™ capture the reasoning process of how engineers design parts not just the knowledge or rules of Knowledge-Based Engineering. Reasoning Engineers look at engineers' design processes and automate this. Reasoning Engineers look at not just the rules the Engineers use, but also their process of going from application to application in search of an optimal design.

Human Interaction

Engineers have insight into how to search for an optimal design. They have intuitions regarding: (1) how to modify (e.g. increments and directions) from one design to another; (2) which previous design cases are similar to the current design problem; (3) areas of a design space that are most promising to search; and (4) ways to level and layer a design search. User can effectively interact with NuEngineer's tools to intuitively control search in these ways.

As search progresses users can dynamically redirect the search including the introduction of new applications into the search.

Intelligent Engineering Paradigms

Throughout this white paper, we have referred to numerous different Artificial Intelligence, Knowledge-Based Engineering, and Optimization techniques. We have been using the term Intelligent Engineering Paradigms to group this diverse set of techniques. Refer to the NuEngineer users guide (available on the web at www.numan.com) for brief descriptions (in the sections: using, examples, and wizards) on how to use NuEngineer to emulate Heuristic Search, Genetic/Evolutionary Algorithms, Cultural Algorithms, Optimization (including classical optimization), Neural Networks, Case-Based Reasoning and Classification.

Numan Intelligence, Inc. provides consulting services on how NuEngineer can be used to create meta-levels of reasoning for many Intelligent Engineering techniques including optimization, AI, OO, PDM, EAI, KDD.

Rules

NuEngineer can be used to create meta-control layers for many Artificial Intelligence techniques not mentioned above. This includes Expert Systems/Knowledge Based Systems and Fuzzy Logic systems. These systems search through rule sets. NuEngineer can be used to direct the search through the rule sets including leveling and layering rule sets.

Applicability of NuEngineer

NuEngineer is not just for engineering. NuEngineer can be applied to almost any problem where human intelligence is used. This includes: simulation, test data correlation, retail stocking, stock markets, pharmacology, chemical engineering, materials engineering, geological simulations for mining and oil exploration, electronic circuit layout, planning, scheduling, actuarial prediction, animation path creation, transportation loading and routing, data searching of partially ordered data bases, architecture, and many others.

Future

NuEngineer can potentially underlie any intelligent system such as vision, speech, language, and robotic systems. Because NuEngineer's operational control elements underlie most other Artificial Intelligence systems, it is possible that NuEngineer will become the new base Intelligence System analogous to Windows and Unix being base Operating Systems.

Conclusions

In summary, NuEngineer provides unparalleled intelligent optimization capabilities within and across engineering applications. NuEngineer's enabling technologies include: NuEngineering (Engineering Design, Analysis, and Search); Engineering Application Integration; Human Computer Intelligence; and Intelligent Evolution including Meta-Reasoning. Many current Intelligent Engineering Paradigms can be further enhanced with a meta-reasoning layer created with NuEngineer.

The advances provided by NuEngineer are unprecedented. Return on investment is dramatic. Design cycles reduce from months to days. Extensive savings in labor costs are realized and turn around times reduce beyond the most demanding expectations. Better designs ensue because the engineering analyses and design processes are not only documented — they are automated. With NuEngineer, engineers go from designing parts to designing methodologies which design parts.

More information on NuEngineer is available on the web at www.numan.com

Some of the issues described above are forward looking and rely upon the expected introduction of certain NuEngineer enhancements.