

The Science of Interaction Design

Presented by Doug Bowman

This part of the tutorial deals with some high-level issues regarding the methodology that one should use for design & evaluation of interaction techniques. Ivan's lecture on the art of interaction design told us about intuition, creativity, and other "artistic" processes that can lead to innovative design. However, not all design is based on a flash of insight. Sometimes, systematic & structured techniques can lead to designs that achieve performance, usability, and usefulness.

A presentation slide with a dark background. At the top left, there is a graphic of a human eye with glowing blue and purple lines radiating from it. The text '3D User Interface Design' is at the top center, with 'fundamental techniques, theory and practice' below it. The main title 'Conflict or complement?' is in large orange font. Below it is a bulleted list of four points in white text. At the bottom, there is a footer with 'Doug Bowman', 'The Science of Interaction Design', the number '2', and a '200 SIGGRAPH' logo.

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Conflict or complement?

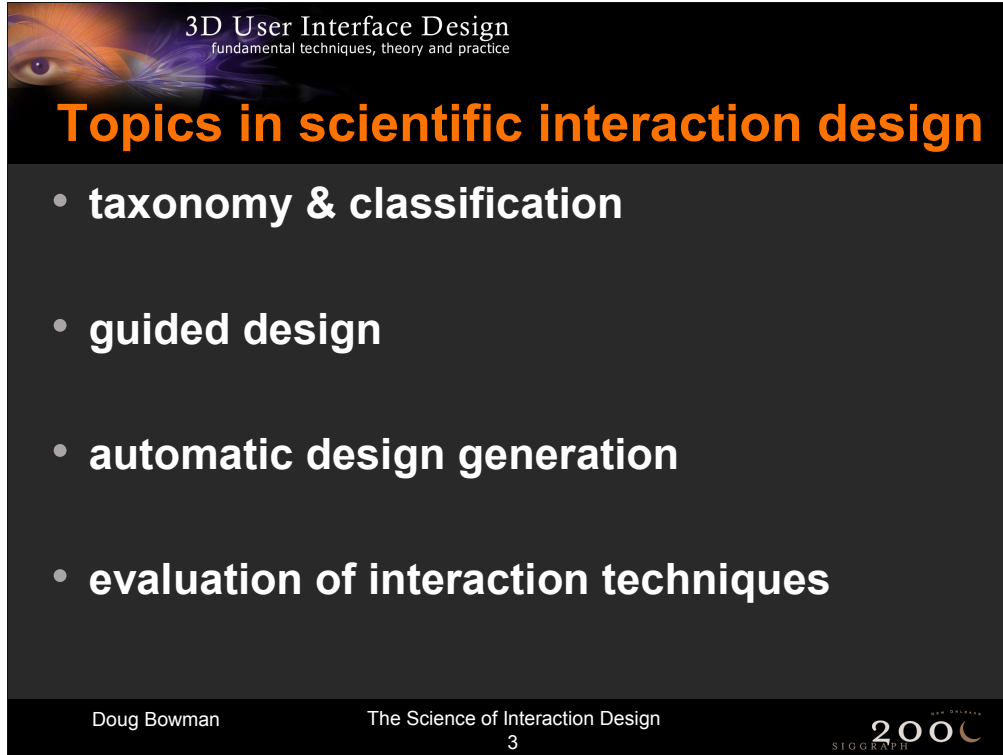
- **art/intuition & science can be seen as conflicting or competing ideas**
- **they can also be seen as complementary**
- **intuition can spark new science**
- **systematic science can spark new creativity**

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Art & Science do not have to be viewed as conflicting ideas. They may seem to be because of the differences between the temperaments and cultures of scientists and engineers as opposed to artists, architects, writers, etc.

However, we can view the two camps as complementary. Often, intuition is needed to open up a whole new area for scientific exploration (e.g. Archimedes' "Eureka"). On the other hand, systematic science can lead to opportunities for creativity (e.g. Einstein's revolutionary theory of relativity was based on decades of his own and others' hard scientific research).

Therefore, we want to try to understand both aspects.

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Topics in scientific interaction design

- taxonomy & classification
- guided design
- automatic design generation
- evaluation of interaction techniques

We will cover four main topics during this lecture:

1. Taxonomy & classification: this is the study of placing things into categories for the purpose of a deeper understanding and a structure within which we can work. We can do this with interaction techniques to give order and structure to our research.
2. Guided design: the idea of using a taxonomy to generate ideas for designing new interaction techniques.
3. Automatic design generation: taking guided design one step further by “implementing” a taxonomy and allowing a computer system to automatically create new interaction techniques.
4. Evaluation of ITs: this is a *design* topic because the results of evaluation should influence the next round of design.

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Taxonomy

- **the science of classification**
- **science example: biological creatures**
- **here: classifying interaction techniques for a task**
- **goals:**
 - deeper understanding of task & technique
 - framework for discussion
 - framework for design
 - framework for evaluation

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The word “taxonomy” really means the science of classification, but it has also come to be used to mean “a particular classification”.

It helps us understand the task at a more detailed level, and understand how certain techniques address the task.

It allows us to use a common framework and vocabulary when discussing tasks/techniques.

It gives us a way to create new techniques (certain types of taxonomies – see later slides).

It gives us a systematic way to evaluate techniques.

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Category-based taxonomy

- group elements into categories of related items
- might be found by cluster analysis
- for ITs, the categories may be metaphor-based

Task
Metaphor
Specific Technique

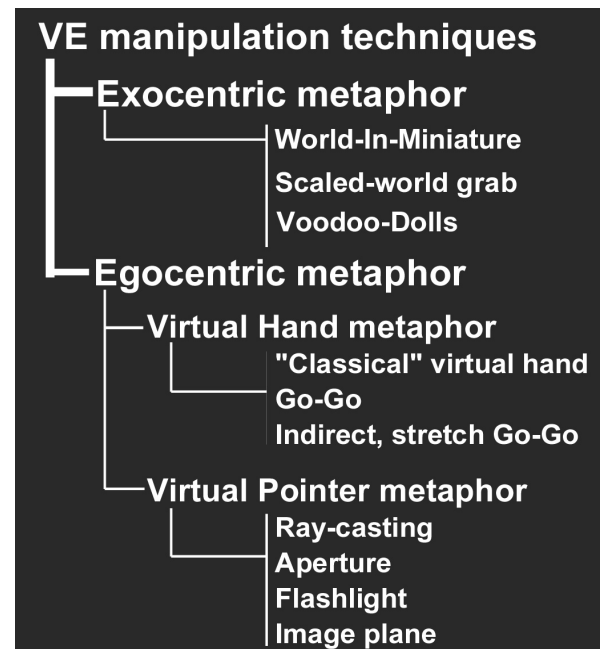
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The category-based type of taxonomic structure for interaction techniques is based on various metaphoric categories. It's just a grouping of related items. There may be several levels of categories and sub-categories, but only one level is presented in this picture for simplicity. For example, two selection/manipulation techniques are Go-Go and Indirect Stretch (virtual arm grows or retracts when buttons are pressed). These can both be classified as "arm-extension" techniques.

The biological taxonomy of creatures has aspects similar to this – all animals are classified as either vertebrate or invertebrate, for example.

Poupyrev's taxonomy of manipulation techniques (at right) is a category-based taxonomy.



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Hierarchic decomposition

- perform task analysis
- partition task into lower-level subtasks
- list technique components for each lowest-level subtask

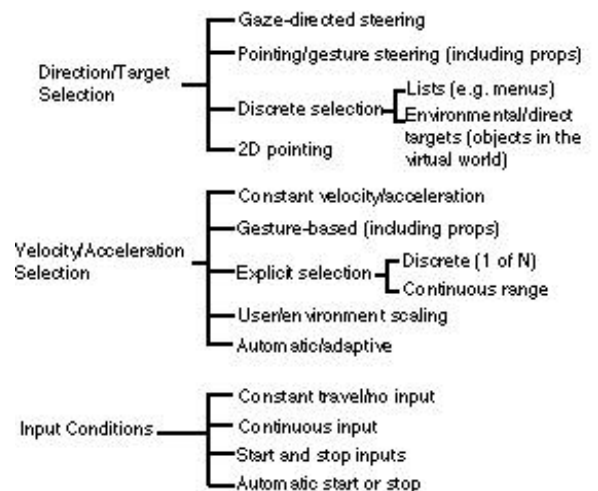
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Hierarchic decomposition is a second type of taxonomy which imposes a different type of structure on the space of interaction techniques. A decomposition is based on task analysis, where a high-level task is partitioned into lower-level subtasks. Technique components are pieces of an interaction technique that satisfy each of the lowest-level subtasks.

Thus, in this type of taxonomy you don't get information about the similarity of two interaction techniques, because complete ITs are not represented here (only smaller components are represented). This type is useful in other ways, however, as we'll see in later slides.

The first taxonomy we presented for the task of travel (picture at right) is an example of this type of taxonomy, as is Bowman's taxonomy of selection & manipulation techniques.



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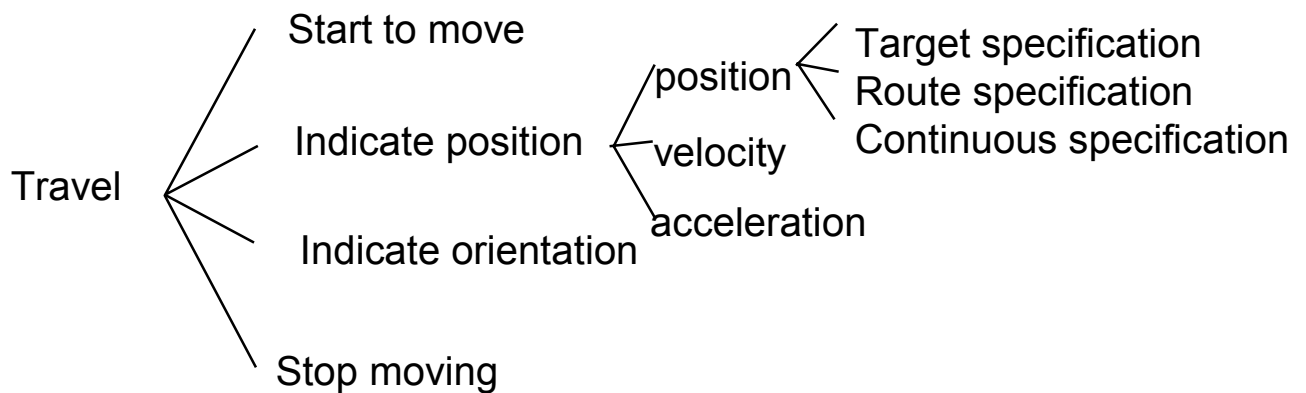
Hybrid taxonomies

- 2 basic types can be combined
- initially partition task into sub-tasks
- create metaphoric categories for each sub-task
- classify techniques by metaphor within sub-task

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Taxonomic structures can be created that combine both types. Here, for example, the task is broken into two sub-tasks, and there are several metaphors listed for each. Technique components are then classified by metaphor. For example, in a travel task, one might consider setting viewpoint position and setting viewpoint orientation to be the two subtasks. Steering, target-based travel, and route planning are three metaphors for the position subtask, as we discussed earlier.



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Guided design

- uses taxonomic structures to aid in the design process
- classification shows holes in design space
- build new techniques by combining components for each of the sub-tasks

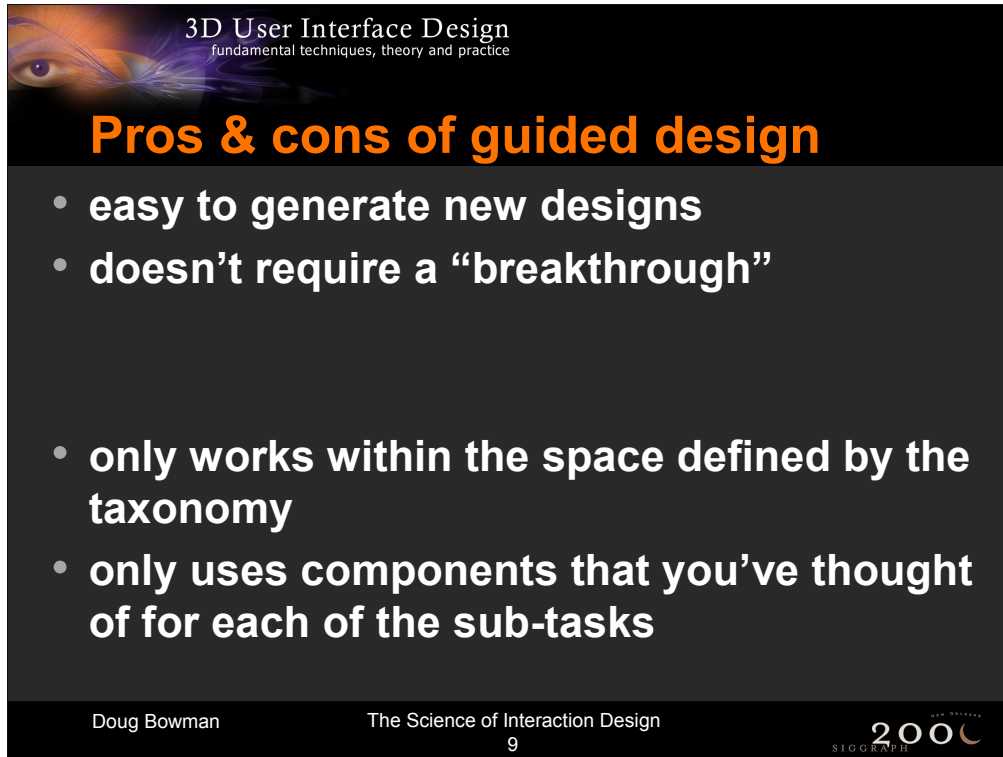
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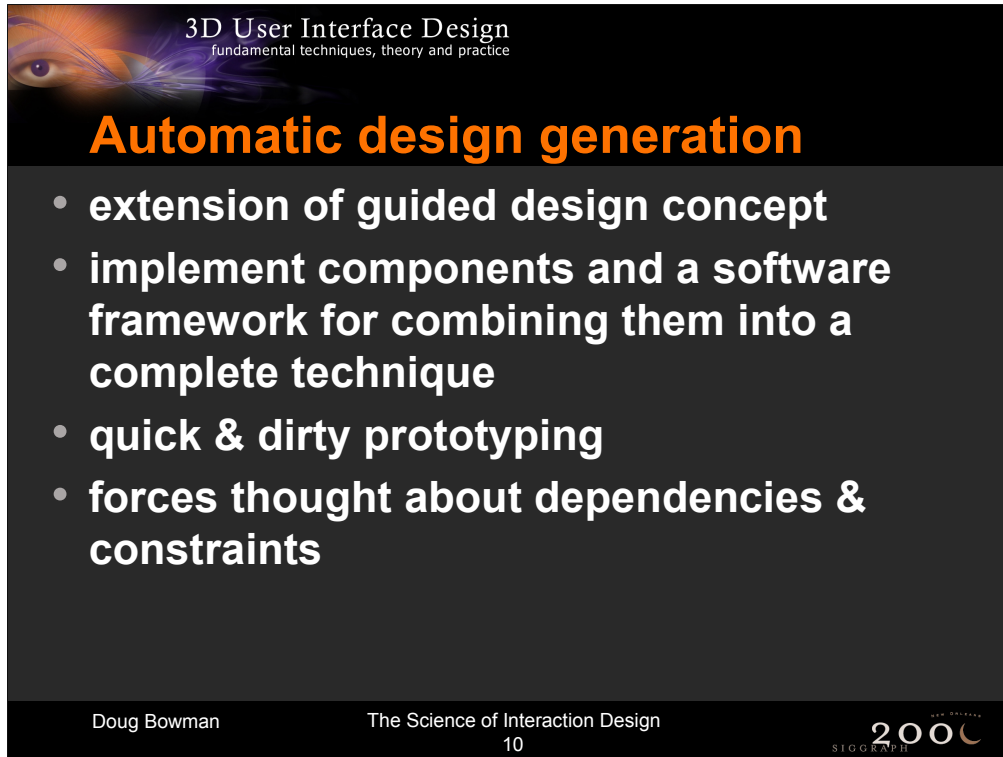
The process of guided design uses the taxonomic structures to quickly create new technique designs. It is based on the idea that a taxonomy defines a design space. By classifying existing interaction techniques within our structure, we can easily “see” where the holes in the design space are – that is, what hasn’t been tried yet. In a hierarchical decomposition, a technique consists of combining one component for each of the lowest-level subtasks, such as the components labeled 1-4 in the picture. So, we can create new techniques simply by choosing a component for each of these subtasks. The example taxonomy given here only defines a design space of 6 techniques, but most real-world taxonomies suggest hundreds of possible techniques

The idea of using a taxonomy as a design space and visualizing the “holes” comes from the classic paper: Card, Mackinlay, and Robertson, The Design Space of Input Devices, CHI '90.

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Guided design makes it very easy to generate new IT designs, because it's been reduced to simply a combinatorics problem. You don't have to have a flash of insight to create a new technique.

However, the designs you generate using this method are only as good as the taxonomy you've created. If you've misrepresented the task decomposition, or not listed important components, your design space will not be correct or complete. Also, not all combinations of components will result in a viable technique – there are dependencies and constraints that limit the real design space. Finally, you may end up with a large number of unusable designs, but this is the price you pay for the quick generation of many technique designs.

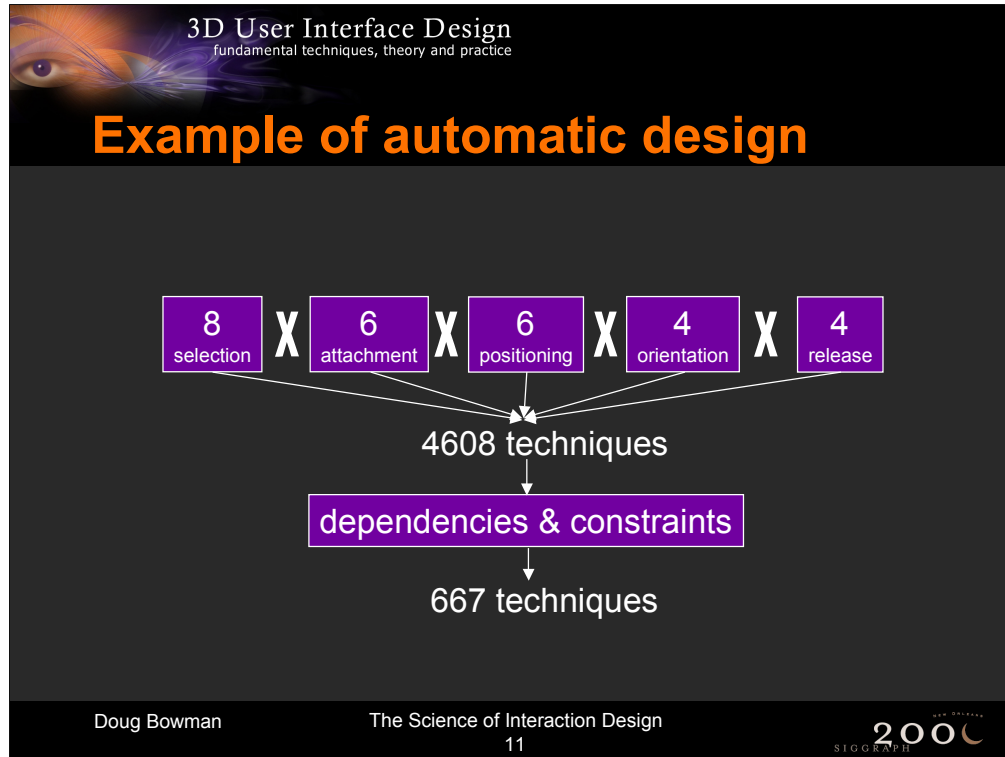
A presentation slide with a dark background. At the top left, there is a graphic of a human eye with glowing blue and purple lines radiating from it. The text '3D User Interface Design' is in white, with 'fundamental techniques, theory and practice' in a smaller font below it. The main title 'Automatic design generation' is in large, bold, orange letters. Below it is a bulleted list of four items in white text. At the bottom, there is a footer with 'Doug Bowman', 'The Science of Interaction Design', the number '10', and a logo for '200 SIGGRAPH'.

Automatic design generation

- extension of guided design concept
- implement components and a software framework for combining them into a complete technique
- quick & dirty prototyping
- forces thought about dependencies & constraints

Automatic design involves an implementation of the guided design concept in software. Technique components are programmed as modules, and then linked together in a framework that mirrors the taxonomy. In this way, a user can automatically combine arbitrary technique components and test the resulting techniques.

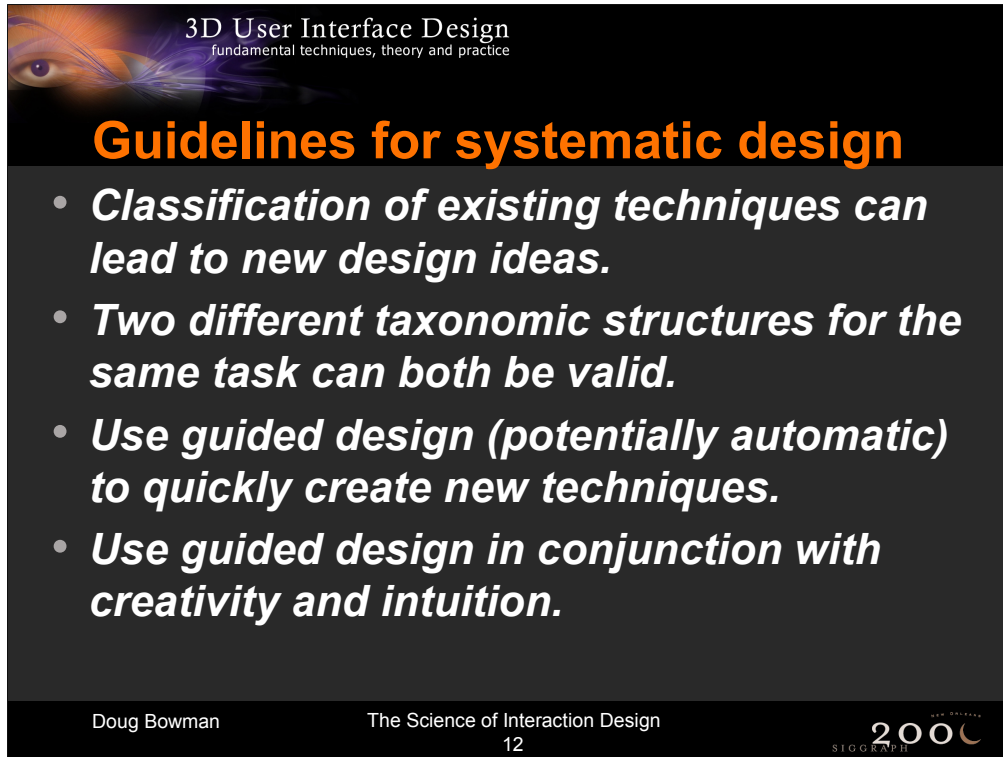
This is very difficult to do in practice, and requires that the taxonomy be well-thought-out and that the sub-tasks and components be relatively orthogonal (there is not overlap between components or sub-tasks). If it can be done, however, this is an excellent way to do rapid prototyping of interaction techniques. It's not always clear just from thinking about it how a new technique design will work in practice. Such a system should be connected with a generalized environment that lets you test the task you're interested in.



We implemented an automatic design system for selection/manipulation techniques, based on our taxonomy of such techniques. Five subtasks (shown) were considered, and several technique components for each subtask. This resulted in 4608 possible techniques, but because the taxonomy inherently has dependencies and constraints, the system can really generate 667 techniques. This gives us a large space to explore.

An example of a dependency: if the user is scaled up when an object is selected, he/she should be scaled back to normal size when the object is dropped.

As far as we know, this is the only automatic design generation system developed for 3D interaction techniques (and possibly for interaction techniques in general). Implementing something like this in the context of a toolkit for developing VE applications would be invaluable to developers.

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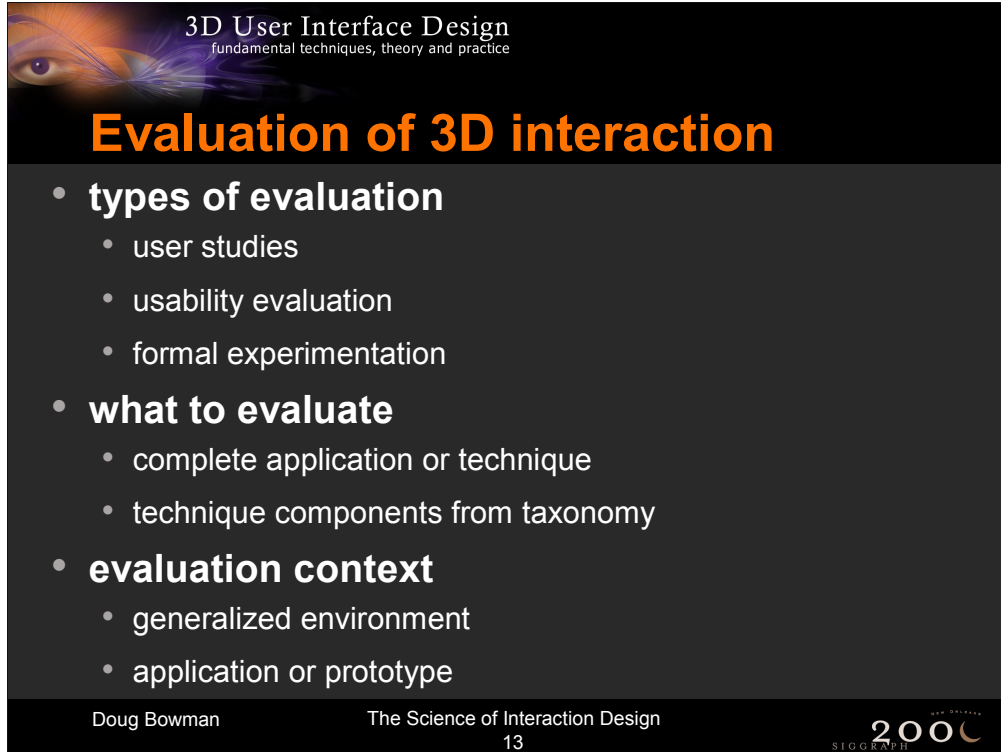
Several guidelines for designing 3D interaction techniques scientifically:

Creating a taxonomy can be time-consuming, but very useful. It forces you to think about the task and the techniques more deeply than you normally would, and can lead directly to new ideas for techniques. Doing this in a group is especially helpful.

Taxonomies, in the sense we are using them, are not “correct” or “incorrect”. The only important metric for the taxonomies we create is their **usefulness**. We presented multiple taxonomies for the tasks of travel and manipulation, all of which were useful in different ways.

The concept of guided/automatic design can be a great help in the rapid development and prototyping of new interaction techniques. It has drawbacks, as we have discussed, but the advantages can be tremendous.

The systematic design processes are not as useful by themselves as they are in conjunction with the more artistic design methods. The two approaches should inform one another.

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Evaluation of 3D interaction

- **types of evaluation**
 - user studies
 - usability evaluation
 - formal experimentation
- **what to evaluate**
 - complete application or technique
 - technique components from taxonomy
- **evaluation context**
 - generalized environment
 - application or prototype

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We also want to talk about evaluation of 3D interfaces and interaction techniques. Until recently, there has been a lack of evaluation in this field. This led to a situation in which we had a lot of interaction techniques and some general thoughts about their advantages and disadvantages, but very little hard data about their performance, usability, and usefulness. Now that the pace of new ideas for 3D interaction techniques seems to be slowing, more attention is being paid to systematic evaluation. We include information about evaluation in the context of a lecture on systematic *design* because evaluation should be a natural part of the iterative design process. We have presented many evaluation results in the previous lectures, but there will always be more evaluation to perform. Therefore, you should follow existing guidelines and results when developing, but nothing can take the place of doing your own user evaluation. Most of this information is directly adapted from evaluation and usability engineering methodologies from traditional HCI. See, for example, Hix & Hartson, *Developing User Interfaces*, Wiley, 1993.

There is a range of types of evaluation we can consider. User studies are usually the least formal, and may include observing users with your system, asking questions of them, and generally allowing exploratory use. These work best in the early stages of development. Usability evaluations are slightly more formal, and usually have an experimental protocol in which the user is given specific tasks to perform with the system. Errors and timings are noted, as are any frustrations or problems the user has. You may ask the user to “think out loud” (verbal protocol) as they work. A formal experiment is usually done in a generalized system – not a particular application. You define independent and dependent variables, take quantitative and qualitative measurements, perform statistical analysis on the results, and so on. This type of experiment is usually reserved for basic research into interaction, not in the context of the development of an application.

There is also the question of what the object of evaluation is. At the highest level, you can evaluate an application in full. You may also evaluate the interaction techniques used in an application. If you’re being more formal, you can test at the level of technique components from the taxonomy in order to understand performance in a more fine-grained way. This is what we mean by using a taxonomy as a framework for evaluation.

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Using taxonomies for evaluation

- Taxonomy is a framework for evaluation
- Evaluation results at a more fine-grained level (evaluate technique components instead of complete techniques)
- Can lead to predictive power for performance of untested techniques

Techniques:
AC (15)
AD (10)
BC (20)
BD ??

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Taxonomies can be used as a framework for evaluation, as we have discussed. This not only means that you can design evaluations based on the structure given by a taxonomy, but that you can predict performance based on this structure as well.

Here's an example of predictive power:

Task: changing the color of an object

Subtasks: selecting object, selecting color

Technique components for object selection: pointing (A), choosing from list (B)

Technique components for color selection: RGB sliders (C), 3D RGB cube (D)

Technique 1: AC (measured to take an average of 15 seconds)

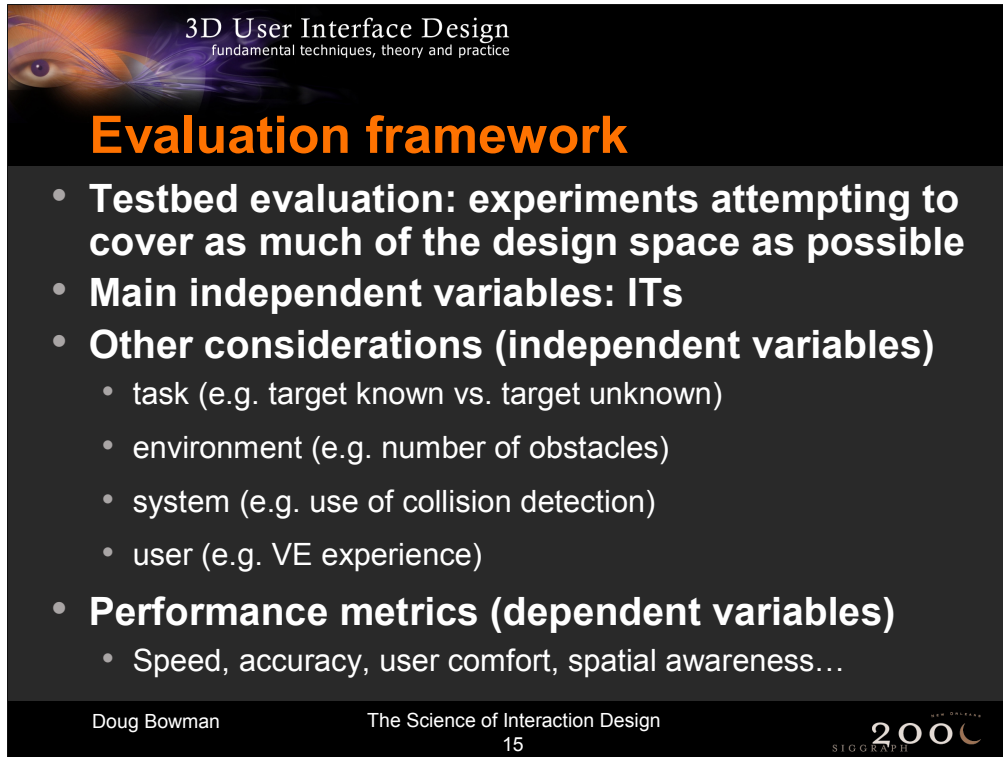
Technique 2: AD (10 seconds)

Technique 3: BC (20 seconds)

Technique 4: BD (not evaluated)

We can infer that component D takes 5 seconds shorter than C, and that B takes 5 seconds longer than A.

So BD can be calculated as $AD+5 = 15$ seconds, or $BC-5 = 15$ seconds.

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Evaluation framework

- **Testbed evaluation: experiments attempting to cover as much of the design space as possible**
- **Main independent variables: ITs**
- **Other considerations (independent variables)**
 - task (e.g. target known vs. target unknown)
 - environment (e.g. number of obstacles)
 - system (e.g. use of collision detection)
 - user (e.g. VE experience)
- **Performance metrics (dependent variables)**
 - Speed, accuracy, user comfort, spatial awareness...

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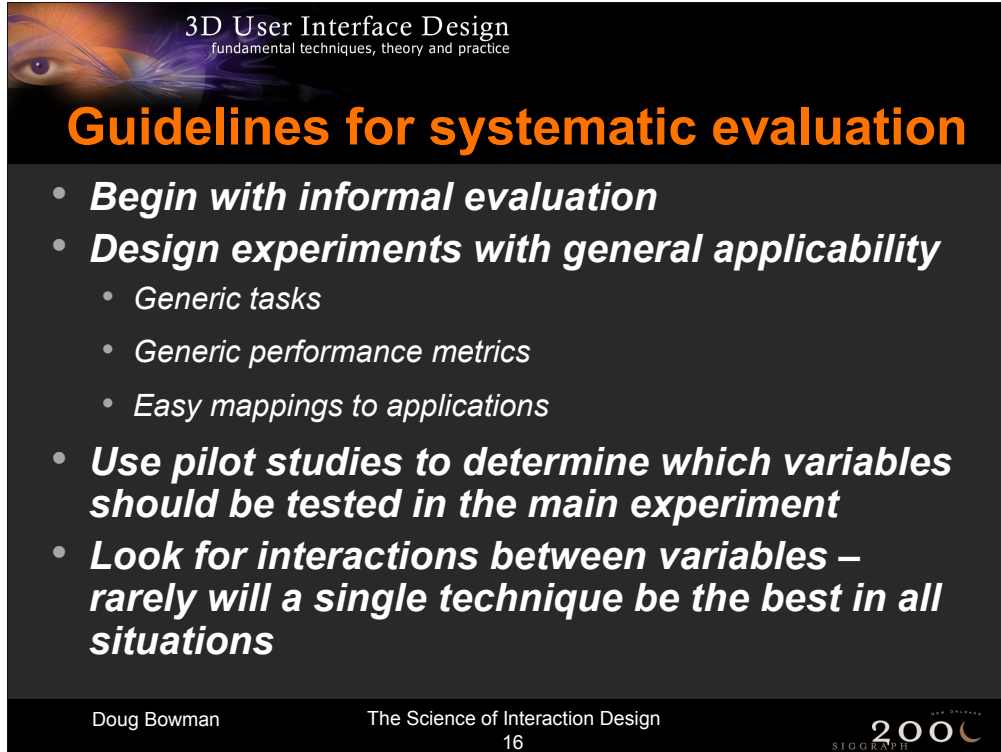
An evaluation testbed is a generalized environment in which many smaller experiments or one large experiment can be run, covering as much of the design space as you can. Like other formal experiments, you're evaluating interaction techniques (or components), but you also include other independent variables that could have an effect on performance. These include characteristics of the task, environment, system, and user.

You also measure multiple dependent variables in such experiments to try to get a wide range of performance data. Here we use performance in the broader sense, not just meaning quantitative metrics. The more metrics you use, the more applications can use the results of the experiment by listing their requirements in terms of the metrics, then searching the results for technique(s) that meet those requirements.

Doug Bowman performed such evaluations in his doctoral dissertation, available online at: <http://www.cs.vt.edu/~bowman/thesis/>. A summary version of these experiments is in this paper:

Bowman, Johnson, & Hodges, Testbed Evaluation of VE Interaction Techniques, ACM VRST '99

Also see: Poupyrev, Weghorst, Billingham, and Ichikawa, A Framework and Testbed for Studying Manipulation Techniques, ACM VRST '97.

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Guidelines for systematic evaluation

- ***Begin with informal evaluation***
- ***Design experiments with general applicability***
 - *Generic tasks*
 - *Generic performance metrics*
 - *Easy mappings to applications*
- ***Use pilot studies to determine which variables should be tested in the main experiment***
- ***Look for interactions between variables – rarely will a single technique be the best in all situations***

Here are some guidelines for evaluating interaction techniques:

Informal evaluation is very important, both in the process of developing an application and in doing basic interaction research. In the context of an application, informal evaluation can quickly narrow the design space and point out major flaws in the design. In basic research, informal evaluation helps you understand the task and the techniques on an intuitive level before moving on to more formal classifications and experiments.

If you're going to do formal experiments, you want the results to be as general as possible. Thus, you have to think hard about how to design tasks which are generic, performance measures that real applications can relate to, and a method for applications to easily re-use the results.

In doing formal experiments, especially testbed evaluations, you often have too many variables to actually test without an infinite supply of time and subjects. Small pilot studies can show trends that may allow you to remove certain variables, because they do not appear to affect the task you're doing.

In almost all of the experiments we've done, the most interesting results have been interactions. That is, it's rarely the case that technique A is always better than technique B. Rather, technique A works well when the environment has characteristic X, and technique B works well when the environment has characteristic Y. Statistical analysis should reveal these interactions between variables.