# Causal Temporal Order in HCI

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## Abstract

This paper proposes applying principles of human causal reasoning to graphical interface design to make interfaces more intuitive. In particular, we present a design guideline for making graphical interfaces consistent with causal temporal order and demonstrate its effectiveness in an experiment where participants solve a puzzle with a novel interface. We also present preliminary results of its application to a text formatting task and propose several other causal principles that are directly applicable to interface design.

## Keywords

Causal reasoning, Human factors, Graphical user interfaces (GUI), Software psychology

## ACM Classification Keywords

H.1.2 [User/Machine Systems]: Software psychology; H.5.2 [User Interfaces]: Graphical User Interfaces (GUI).

## General Terms

Human Factors, Design, Experimentation

## Introduction

A central theme of human-computer interaction is capitalizing on users' knowledge of the real world to make computer interfaces more intuitive. A common approach is to use a specific real world environment, such as a desktop, as a metaphor for guiding interface design [4]. We propose a different approach by appealing to the basic principles of causal reasoning that are common to how people think about all real world environments.

Research has shown that people's causal reasoning is guided by both implicit and explicit assumptions about how causes bring about effects. One such assumption is temporal order: causes precede effects [9]. Others include spatial-temporal contiguity from cause to effect [10,11] and similarity between cause and effect [7]. Causal systems that violate these assumptions are more difficult to learn and use than systems that satisfy them. This work focuses on designing interfaces that are consistent with temporal order. Future work will address other causal assumptions.

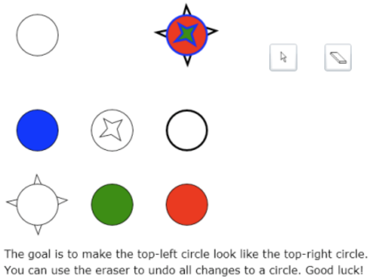
A Graphical User Interface (GUI) can be seen as an illusory causal system which obscures the true causal system: the logic of the underlying program determining what events will occur. Interfaces in accord with causal assumptions provide intuitive interactions by scaffolding upon people's intuitive causal reasoning. For example, consider a computer pinball game. The program could light a bumper before the ball hits it since the ball's trajectory can be calculated in advance. However, this would confuse the user because in a physical pinball game it is the collision, not the trajectory, which causes the bumper to light up. Therefore, the collision must come first.

Causal relations exist not only among events but also among properties. Consider the *Format Painter* in Microsoft® Word which copies the format from one section of text to another. The interaction begins with selecting the source of the format and ends with selecting the destination. This is intuitive because the source determines the nature of the desired change, and therefore it can be conceived as having causal influence over the destination. If the order were reversed, destination before source, the system would be less intuitive.

## Causal Temporal Order

The current research focuses on temporal order, the assumption that causes, either events or stable properties, should precede their effects. It is easier to reason from cause to effect than from effect to cause [14]. People are also better at learning the structure of a causal system when they observe a cause before observing its effects, even when the order of observations is irrelevant [9]. Students even prefer to write mathematical equations according to their causal order [12]. For equations representing multiple causes of a single effect, students choose to structure the equation such that all of the causes lie on one side of the equation and the sole effect on the other. They also find it easiest to understand in this form.

Based on these findings we propose the causal order hypothesis: when selecting objects to participate in a causal event, it will be more intuitive to select objects that function as causes prior to selecting objects that functions as effects. When applied to GUIs, the hypothesis entails that in multiple-step interactions, selecting objects that determine the nature of the change should precede selecting objects that comprise the destination of the change. For example, we argue that making text bold in conventional word processors is unintuitive because a user is required to select the



The goal is to make the top-left circle look like the top-right circle.
You can use the eraser to undo all changes to a circle. Good luck!

**Figure 1.** Text reads, "The goal is to make the top-left circle look like the top-right circle. You can use the eraser to undo all changes to a circle. Good luck!" Participants were able to choose between the default selection tool and the eraser tool.

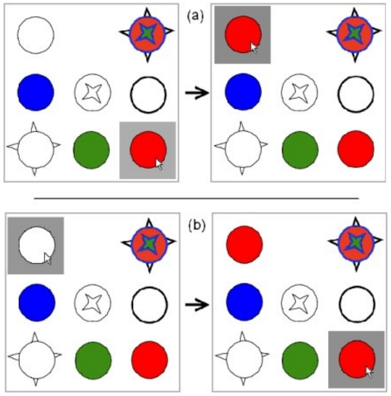


**Figure 2.** Coloring the blank object red in both conditions. (a) In the destination-last condition, the participant must first click the red object, then the blank object. (b) In the destination-first condition, the participant must first click the blank object, then the red object.

text before clicking the bold button. Because people naturally think in order of cause to effect, such interactions would be more intuitive if the event of choosing the object meant to change (selecting the text) comes after events determining the nature of the change (clicking the bold button).

## Related Work

One method for capitalizing on users' causal knowledge of the physical world is to use a physical environment metaphor. Technological advancements are enabling GUIs that are not only inspired by physical systems, but either simulate or incorporate them. BumpTop [1] is a desktop interface in which users can manipulate their files as if they were physical objects that can be stacked or tossed around the virtual desktop. Tangible user interfaces and augmented reality go further to make physical objects a central part of the interface itself [3]. These interfaces, as well as others based on real-world metaphors, naturally satisfy causal assumptions. However, there exist no general principles on how to build such interfaces for any given application. The BumpTop interface is inappropriate for a word processor, and it is not clear how to build a tangible spreadsheet. Our aim is to derive general design principles that apply to a wide range of applications.

Applying cognitive theories to generate guidelines for good interface design is not a new technique, e.g. [13]. However, as far as we know, principles of causal reasoning have not yet been used for this purpose. Instead, they have been applied to modeling users' understanding of individual interfaces [6]. The innovation in our work lies in applying principles of causal reasoning to generate simple, widely applicable design guidelines. Some such guidelines will correspond to what is already known, e.g. the importance of immediate feedback. However, others will be novel, including the causal order hypothesis. These guidelines are not meant to replace other cognitively motivated guidelines, but to supplement them.

## Experiment 1

This experiment tests the causal order hypothesis by asking participants to solve a puzzle with a novel interface (see Figure 1). In this puzzle, a property is transferred from one object to another either by selecting the source first and then the destination, or by selecting the destination first and then the source. Each object has a unique, intrinsic property (e.g. red color) that can be applied to other objects. The property from the source object is either copied to the destination object or it modifies the destination object's intrinsic property. For example, if the source is the red object and the destination is the thick-border object, an interaction causes the border on the thick-border object to become red. Modified properties can then be applied to other objects. If the thick-border object is now applied to the blank target object, the target object will also get a thick red border. The goal of the puzzle is to give the target object a specific set of properties.

In the destination-last condition clicking on object A and then clicking on object B applies the property of object A to object B. Thus, for each causal event, the first object clicked is the source and the second object clicked is the destination. In the destination-first condition the order is reversed, the first object clicked is the destination and the second object clicked is the

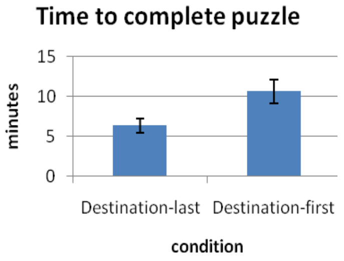


**Figure 3.** Participants in the destination-last condition solved the puzzle 40% faster than those in the destination-first condition.

source (see Figure 2). The source has the role of cause in the activated causal link because it determines the nature of the change, while the destination has the role of effect because it is what changes. Therefore, the destination-last condition is consistent with causal order and the destination-first condition is inconsistent.

Participants were only told the goal of the puzzle and how to use the eraser tool to return an object to its initial condition. They were expected to learn how the system works by interacting with it.

*Methods*

The puzzle was implemented using Microsoft Silverlight. We recorded time and number of clicks to solve the puzzle. Participants were recruited through Amazon® Mechanical Turk. 17 participants were assigned to the destination-last condition, and 16 to the destination-first condition. The fastest 10% of solvers in each condition received a bonus. Participants could take as much time as needed, but after 10 minutes were offered (without forewarning) the opportunity to quit without penalty.

*Results*

All participants in the destination-last condition solved the puzzle, compared to only 63% of participants in the destination-first condition ($p<.006$, binomial test). We included participants' quitting time as a lower bound on how long it would have taken them to solve the puzzle.

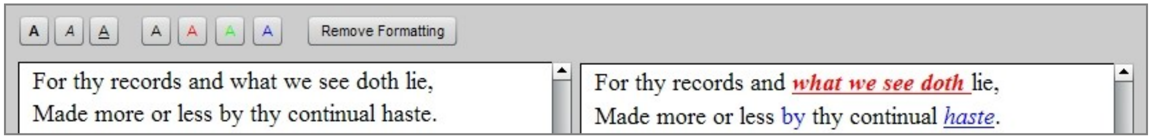
Participants in the destination-last condition completed the game in less time ($t=2.46$, $p<0.03$, $M=6.35$ minutes, $SD=3.68$) and fewer clicks ($t=3$, $p<0.01$, $M=151$ clicks, $SD=96.84$) than participants in the destination-first condition ($M=10.63$ minutes, $SD=5.97$, see Figure 3; $M=282$ clicks, $SD=140.60$).

These results support our hypothesis that an interface is easier to use when it is consistent with causal order. Participants took longer to complete a task with a novel interface when the interface dynamics were inconsistent with natural causal order.

## Discussion

The interface in this experiment was designed to be novel. It is not analogous to any system, physical or digital, that participants might have had experience with. Therefore, the causal order principle is not grounded in any specific metaphor and we expect it to apply to a wide range of applications.

In order to make the causal structure of the aforementioned puzzle difficult to learn, we did not segregate objects into interface components (e.g. bold button) and content components (e.g. text) as is typical in point-and-click GUIs. On one hand, traditional GUIs may garner minimal benefit from adherence to causal order given that the interface objects always act as causes and the content objects always act as effects. On the other hand, obeying causal order could aid in removing this object-type distinction in order to design more flexible and easily customizable interfaces.



For thy records and what we see doth lie,
Made more or less by thy continual haste.

For thy records and ***what we see doth*** lie,
Made more or less by thy continual *haste*.

**Figure 4.** A to-be formatted document. Participants were asked to use the toolbar to format the text on the left such that it matched the text on the right.

The causal order hypothesis is related to the debate between *verb-noun* and *noun-verb* order in graphical interfaces [5]. Verb-noun refers to interactions where the user selects the action to be taken before selecting the object to be acted upon. Noun-verb refers to interactions where the user selects the object to be acted upon before selecting the action. The causal order hypothesis suggests that verb-noun interactions are generally preferable to noun-verb interactions, although other relevant factors may override this prescription. Noun-verb order is common in modern GUIs, e.g. context menus. The causal order hypothesis suggests that even when there are other advantages to noun-verb interactions [8], the order itself will be less intuitive.

Verb-noun order, which is consistent with causal order, can often be found in the form of tools [2]. For example, you select the brush in a drawing program before applying the brush to the canvas. It follows then from our hypothesis that tool-based interfaces tend to be intuitive.

## Ongoing and Future work

We want to test whether the causal order hypothesis holds in more typical interfaces. Thus, our second experiment asks users to perform a common task: formatting text. The design of the experiment is not yet finalized, so we present only preliminary results in which most differences are not statistically significant.

In general, word processors require selecting text before applying styles to it. This order is causally inconsistent. Thus, we created a text-formatter (see Figure 4) and manipulated whether the order was consistent with conventional word processors (text-first) or with the causal order hypothesis (text-last). We used a GOMS-style analysis to identify format distributions for which the number of actions is equated across the two conditions and used that distribution to generate formatted texts. We then asked participants to use one interface or the other to format plain text to match the formatted text.

18 participants were given 30 minutes to format up to 10 documents (each containing two of Shakespeare's sonnets, approximately 230 words). Unlike the previous experiment, participants here received detailed instructions on how to use the interface.

While the preliminary results are not significant, they are promising. Participants in the text-last condition were over a minute slower on the first document (as expected due to prior experience with the text-first order). Averaged across all documents, however, the text-last condition was just as fast (6.9 minutes/document) as the text-first condition (7.7

minutes/document). We think that with a longer experiment, design improvements that reduce variance, and a larger sample, the text-last condition will be significantly faster than the text-first condition. In addition, at the end of the task participants in the text-last condition rated the interface as easier to use than those in the text-first condition.

Another future goal is to tease apart the role of attention from the role of causal order. Because intended changes occur at the destination, acting on the destination object last requires fewer shifts of attention. Finally, we plan to explore the application of other causal principles, including contiguity and similarity.

## Conclusions

This research has demonstrated the utility of applying the psychology of causal reasoning to GUI design. People reason from cause to effect more easily than they reason from effect to cause, and we translate this finding into a recommendation for designing interactions: selecting the destination of a change should follow selecting the nature of the change. We demonstrated the effectiveness of this recommendation and have begun applying it to real-world interfaces.

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