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## Rejoinder

# Response to Comments on "Website Morphing"

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Website morphing draws on the Expected Gittins' solution to a partially observable Markov process, on the rapid consumer-segment updating with Bayesian methods, and on matching a website's look and feel to a visitor's cognitive style. In each area there are exciting research opportunities including optimality in the presence of switching costs (within a visit), Bayesian updating of cognitive styles across websites, extensions to other segmentation schemes such as cultural styles, morphing of other website characteristics such as advertising, and applications to other media such as smartphones.

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We are honored to receive excellent constructive suggestions from luminaries such as Andrew Gelman, John Gittins, and Hal Varian. Our research has built on seminal contributions by each of these authors. We hope we have contributed modestly to the use of "bandit" problems to select a website's look and feel, to the use of Bayesian inference to identify a website visitor's cognitive-state-dependent preferences, and to the interesting issues of experimentation, optimization, and personalization in the customization of websites. Each of these authors provides unique insights.

## Expected Gittins Indices

Multiarm bandit problems were once considered too difficult to solve until Dr. Gittins proved that index strategies would work. Indeed, in an address to the Royal Statistical Society (February 14, 1979), the great statistician Peter Whittle opened:

> [The bandit problem] was formulated during World War II, and efforts to solve it so sapped the energies and minds of Allied analysts that the suggestion was made that the problem be dropped over Germany, as the ultimate instrument of intellectual sabotage.

When cognitive states are known, the Gittins strategy provides an *optimal* strategy for assigning morphs to visitors. This optimality balances exploration and exploitation, and takes all opportunity costs into account, including potential misassignments. When cognitive states are known only probabilistically, the expected Gittins heuristic strategy is no longer guaranteed to be optimal. However, past results suggest that any deviations from optimality are small. Dr. Gittins is correct that our statement about testing relative to a no-morph strategy refers to the *expected* Gittins index (close to optimality), not the Gittins index (always optimal).

Optimality might also suffer for reasons outside our model. For example, visitors might be confused if they receive too many morph changes.[1] When such "switching costs" are incurred, the optimization is no longer indexable but can be solved with a multiple-index strategy. We find this new direction exciting.

We also thank John Gittins for highlighting that website applications require discount factors ($a$) that are much closer to 1.0 than typical bandit problems. Dr. Gittins' suggestions for computational efficiency suggest important improvements.

[1] This is one practical reason why we limit morphing to at most one change per visitor.

## Statistical Design of Experiments

Dr. Gelman suggests synergies between (partially observable) bandit problems and the statistical design of experiments. We agree. Expected Gittins indices enable experimenters to select experimental treatments optimally and to do so *on the fly*. Such algorithms have the potential to lead to new adaptive measurement methods in conjoint analysis experiments and/or the optimal assignment of pedagogical lessons in adaptive learning.

We also agree with Dr. Gelman's suggestions for posterior predictive checks (PPCs). In our analysis we use Markov chain Monte Carlo methods to infer a posterior distribution for the preference weights $\Omega$. These weights relate visitors' preferences for click-alternative characteristics to their clickstreams. When feasible, we have used PPCs in our other work. PPCs are likely to be valuable here to examine whether the logit model is consistent with the clickstreams that are observed in the priming study. Although PPCs are computationally intensive for our data set, they represent a valuable research direction. Extending Dr. Gelman's suggestion further, it might also be useful to study the sensitivity of the optimal morph assignment to the posterior distribution of $\Omega$.

## Morphing Beyond Cognitive Styles, and Beyond a Website's Look and Feel

We are pleased that Dr. Varian suggests other applications and suggests other constructs besides cognitive styles that could be used for morphing applications. There are many instances in which website characteristics, product offerings, or software menus respond to users' choices. Adomavičious and Tuzhilin (2005) review the next generation of recommendation systems such as those used by TiVo and by Amazon.com. Cookies within an URL and across URLs enable websites to provide customized content that is designed to increase customer satisfaction and/or sales. We are happy to contribute to this literature.

The Gittins engine provides a rigorous (and optimal) way to assign content, style, or other characteristics while balancing exploration and exploitation. For example, Google Analytics' Website Optimizer relies on experimental designs to identify website characteristics. The Gittins engine can improve the efficiency of such experimentation, and as Dr. Varian points out, the Gittins/Bayesian engines can condition a website's characteristics on partially observable user descriptions.

We thank Dr. Varian for suggesting other user descriptions. The Bayesian engine provides a practical means to identify many unobserved visitor descriptions whether they be cognitive styles (the BT application) or gender (Dr. Varian's example). We are experimenting with persistent user descriptions such as demographics and cultural styles (e.g., hierarchical versus egalitarian cultures, or individualistic versus collective cultures). We hope with experience to determine rules by which the best and most parsimonious descriptions can be matched to applications.

Dr. Varian raises the interesting technical challenge of dealing with the risk of misclassification. In the BT application, we assumed at most one morph per visit. Many morph changes might provide a cognitive penalty. If the website changes too often, the "switching-cost" penalty might overwhelm the advantage to morph-by-cognitive-style matching. Multiple-index strategies provide a means to explore solutions when such switching costs are substantial (Dusonchet and Hongler 2006, Niño-Mora 2008).

Finally, we are excited about opportunities to use information that is available from advertising networks such as DoubleClick. We are actively involved in a project to morph advertising across sessions (allowing for "opt in" or "opt out"). The study will include cognitive styles and other latent customer characteristics. We might also envision morphing across mobile devices (e.g., using customer location for a morph) and social media (e.g., using the customers place in the social network). We are excited by these and other applications.

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