Bayesian Analyses of the Survivor Interaction Contrast

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Andrew Heathcote

Ami Eidels

James T. Townsend

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Bayesian Analyses of the Survivor Interaction Contrast

Joseph W. Houpt, Andrew Heathcote, Ami Eidels and James T. Townsend

Society for Mathematical Psychology Annual Meeting
Columbus, Ohio
July 22, 2012
Outline

1. Introduction
2. Parametric Test
   - Model
   - Simulation
3. Nonparametric Test
   - Model
   - Simulation
4. Comparisons Among SIC Tests
   - Simulation
   - Application
5. Conclusion
Outline

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How do different sources of information combine in mental processing?

- Are both sources used concurrently, or do we use one at a time?
- How many sources are enough to respond?
Salience

- To test architecture and stopping rule, without conflating them with workload capacity, factorially speed up and slow down the processing of each source of information.
Survivor Interaction Contrast

- Indicates architecture and stopping rule.
Survivor Interaction Contrast

- Indicates architecture and stopping rule.
- The SIC is interaction between the salience manipulations.
  - Instead of just using the mean time, we use the survivor function:
    \[ S(t) = \Pr\{ T > t \} = 1 - F(t) \]
    \[
    SIC(t) = [S_{LL}(t) - S_{LH}(t)] - [S_{HL}(t) - S_{HH}(t)]
    \]
    Here, the subscripts indicate the salience of each source of information.
Survivor Interaction Contrast

Parallel

Serial

Coactive

Townsend & Nozawa (1995)
Schweickert, Giorgini & Dzhafarov (2000)

Dzhafarov, Schweickert & Sung (2004)
Houpt & Townsend (2011)
Null Hypothesis Test

Kolmogorov–Smirnov Test

\[ D^+ = \max_t (F_1(t) - F_2(t)) \]

SIC Statistic

\[ D^+ = \max_t (\text{SIC}(t)) \]

\[ D^- = \min_t (\text{SIC}(t)) \]

\[
\lim_{N \to \infty} \Pr\{ \sqrt{N}D^+ \geq x \} = \Pr\{ \sqrt{N}D^- \geq x \} = e^{-2x^2}
\]

\[
N_{KS} = \frac{1}{1/m + 1/n} \quad N_{SIC} = \frac{1}{1/k + 1/l + 1/m + 1/n}
\]
### Introduction

#### Parallel Serial Mean Model

- **Parallel-OR**: $\hat{D}^+ \neq \hat{D}^-$  
  - Coactive: $\checkmark$  
  - Reject null hypothesis    

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- $\checkmark$: Reject null hypothesis  
- $\emptyset$: Fail to reject null hypothesis  

---

Houpt, et al. (SMP 2012)  Bayesian SIC
Shortcomings

- Tests positive and negative deflections *not* SIC form.
  - Requires two separate tests.
- Only can gain evidence against a lack of positive or negative deflection.
- Only get a yes/no answer, not relative evidence.
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   - Application

5. Conclusion
\( f(t) \): Density (PDF) \hspace{1cm} F(t): \text{Cumulative Distribution (CDF)}

Parallel-OR \hspace{1cm} f_{12}(t) = f_1(t)[1 - F_2(t)] + f_2(t)[1 - F_1(t)]
Parametric Test Model

\( f(t) \): Density (PDF) \hspace{1cm} \( F(t) \): Cumulative Distribution (CDF)

Parallel-OR \hspace{1cm} f_{12}(t) = f_1(t)[1 - F_2(t)] + f_2(t)[1 - F_1(t)]

Parallel-AND \hspace{1cm} f_{12}(t) = f_1(t)F_2(t) + f_2(t)F_1(t)
\[ f(t): \text{Density (PDF)} \quad F(t): \text{Cumulative Distribution (CDF)} \]

\begin{align*}
\text{Parallel-OR} & \quad f_{12}(t) = f_1(t)[1 - F_2(t)] + f_2(t)[1 - F_1(t)] \\
\text{Parallel-AND} & \quad f_{12}(t) = f_1(t)F_2(t) + f_2(t)F_1(t) \\
\text{Serial-OR} & \quad f_{12}(t) = pf_1(t) + (1 - p)f_2(t)
\end{align*}
$f(t)$: Density (PDF) \hspace{2cm} F(t): Cumulative Distribution (CDF)

Parallel-OR 
\[ f_{12}(t) = f_1(t)(1 - F_2(t)) + f_2(t)(1 - F_1(t)) \]

Parallel-AND
\[ f_{12}(t) = f_1(t)F_2(t) + f_2(t)F_1(t) \]

Serial-OR
\[ f_{12}(t) = pf_1(t) + (1 - p)f_2(t) \]

Serial-AND
\[ f_{12}(t) = f_1(t) \ast f_2(t) \]
\[ T_{i;H} \sim IG\left(\frac{\alpha}{\nu_H}, \alpha^2\right) \]

\[ T_{i;L} \sim IG\left(\frac{\alpha}{\nu_L}, \alpha^2\right) \]

\[ \alpha \sim \Gamma(4, 0.1) \]

\[ \eta \sim \text{Exponential}(100) \]

\[ \nu_L \sim \Gamma(4, 0.1) \]

\[ \nu_H = \nu_L + \eta \]
\[ T_{i;H} \sim IG \left( \frac{\alpha}{\nu_H}, \alpha^2 \right) \quad \eta \sim \text{Exponential}(100) \]

\[ T_{i;L} \sim IG \left( \frac{\alpha}{\nu_L}, \alpha^2 \right) \quad \nu_L \sim \Gamma(4, 0.1) \]

\[ \alpha \sim \Gamma(4, 0.1) \quad \nu_H = \nu_L + \eta \]

\[
 f_i(t; \nu_i, \alpha) = \sqrt{\frac{\alpha^2}{2\pi t^3}} \exp \left[ -\frac{(t\nu_i - \alpha)^2}{2t} \right]
\]

\[
 F_i(t; \nu_i, \alpha) = \Phi \left[ \sqrt{\frac{\alpha^2}{t}} \left( \frac{t\nu_i}{\alpha} - 1 \right) \right] + \exp \left[ 2\alpha \nu_i \right] \Phi \left[ -\sqrt{\frac{\alpha^2}{t}} \left( \frac{t\nu_i}{\alpha} + 1 \right) \right]
\]
Simulation Parameters

\[ T_i = \inf \{ t : X_i(t) \geq \alpha \} \]

\[ T_i \sim IG \left( \frac{\alpha}{\nu_i}, \frac{\alpha}{\sigma^2} \right) \]

\begin{align*}
\alpha &= 30 \\
\sigma^2 &= 1 \\
p &= 0.5 \\
\nu_H &= 0.3 \\
\nu_L &= 0.1
\end{align*}

Houpt, et al. (SMP 2012)
Simulation Results

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• Approach: Model the response time distributions (as opposed to the RT generating process).

• Assume each RT distribution is an independent sample from a Dirichlet process prior.

• Compare the Bayes factor of each SIC form in the posterior relative to encompassing prior.
- Approach: Model the response time *distributions*
  - (as opposed to the RT generating process).
- Assume each RT distribution is an independent sample from a Dirichlet process prior.
- Compare the Bayes factor of each SIC form in the posterior relative to encompassing prior.

\[
\alpha_i \sim DP(\beta) \\
RT_{l(i)} \sim \alpha_i.
\]
Simulation

- Tested on same models as parametric-Bayesian test (but with 1000 rounds rather than 100).
  - Used region of probabilistic equivalence ±.1 for SIC and ±.3 for MIC.

Houpt, et al. (SMP 2012)
Simulation

- Tested on same models as parametric-Bayesian test (but with 1000 rounds rather than 100).
- Used region of probabilistic equivalence ±.1 for SIC and ±.3 for MIC.

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Example SICs

Serial AND

Parallel OR

Houpt, et al. (SMP 2012)
Comparisons Among SIC Tests

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Houpt, et al. (SMP 2012)
## Comparisons Among SIC Tests

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Comparisons Among SIC Tests

KS Test

- Serial OR
- Serial AND
- Parallel OR
- Parallel AND
- Coactive

DP Test

- Serial OR
- Serial AND
- Parallel OR
- Parallel AND
- Coactive

Houpt, et al. (SMP 2012)
Bayesian SIC
## KS Test

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Houpt, et al. (SMP 2012) Bayem n SIC

25 / 30
## Parametric Bayes

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Houpt, et al. (SMP 2012) Bayesian SIC
## Nonparametric Bayes

### AND Task

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Outline

1. Introduction
2. Parametric Test
   - Model
   - Simulation
3. Nonparametric Test
   - Model
   - Simulation
4. Comparisons Among SIC Tests
   - Simulation
   - Application
5. Conclusion
Overview

- Developed parametric and nonparametric Bayesian tests for architecture and stopping rule.
- Tested each of these approaches on both simulated data and experimental data.
  - Both did quite well on simulated data.
  - Parametric conclusions diverged from NHST and nonparametric tests on human data.
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Thank you.