Sense of Presence and User Interface Usability

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28 March, 2022

Contents

Introduction

This file can be used to reproduce results reported in Chapter 4 of the thesis report. Specifically, these are:

1. Means, 95% highest density intervals, and posterior probability that our hypotheses hold for the likelihood that each sense of presence subscale examined scored higher than the IGroup norm provided in a database of 542 research cases, as presented by Table 4.5 in Section 4.2.3.3.
2. Means, and 95% highest density intervals, of the Component-Based Usability Questionnaire (Brinkman, W.P., Haakma, R., and Bouwhuis, D.G. (2009)), as presented by Table 4.4 in Section 4.2.2.
3. Means, and 95% highest density intervals, of the Additional Usability Questions, as presented by Table 4.4 in Section 4.2.2.
4. Mean, and 95% highest density intervals, of the Ease of Material Collection (EoMC) question, as presented by Table 4.4 in Section 4.2.2.

Theoretical Concepts Descriptions

Highest Posterior Density Interval (HPDI)

Indicates which points of a distribution are most credible and summarizes the distribution by specifying an interval that spans most of it, in our case 95%. Every point inside this interval has higher credibility than points outside it.

Posterior Probability

Probability of an event occurring given the data provided. In the case of our models here, it is the probability that each of our hypotheses is likely to hold given the data used to construct them. extract.samples() method used collects given number of posterior samples from the specified model constructed.

Analysis

Required files: "Data/sop_data.csv", "Data/ipq_DB_means.csv", "Data/cbuq_data.csv", "Data/auq_scores_data.csv".

Output: Knitted PDF (or HTML) with the same name as the script.

Importing Packages

```
library(foreign) # Open various data files
library(tidyr) # For wide to long format transformation of the data
library(ggplot2)
library(pander) # For rendering output
library(rethinking) # map2stan
```

Sense of Presence Elicited by the VR System

Loading Data

```
SoPdf = read.csv("Data/sop_data.csv")
```

Loading IGroup Database Data and Creating a Dataframe to be Used for Comparison

```
SoPDBlist = read.csv("Data/ipq_DB_means.csv")
SoPDBdf <- data.frame( pres = SoPDBlist$X0[1],
                       sp = SoPDBlist$X0[2],
                       inv = SoPDBlist$X0[3],
                       real = SoPDBlist$X0[4]
                       )
```

Sense of Presence Models for Each Sub-Scale

Results here are reported in Table 4.5 of Section 4.2.3.2 in the thesis report.

General Presence

```
set.seed(42)

pres_m <- ulam(
  alist(
    PRES_Score ~ dstudent(v, mu, sigma),
    v ~ gamma(2,0.1),
    mu <- aGeneral,
    aGeneral ~ dnorm(3, 10),
    sigma ~ dexp(1)
  ), data = SoPdf, iter = 10000, chains = 4, cores = 4
)
```

```
precis(pres_m, prob = 0.95)
```

```
##               mean        sd      2.5%    97.5%    n_eff    Rhat4
## v        2.1618600 0.4472891 1.3858635 3.125292 17893.95 1.000252
## aGeneral 4.2585832 0.3013386 3.6611166 4.840538 16655.03 1.000087
## sigma    0.9746485 0.2423941 0.5832568 1.526539 16206.14 1.000059
```

```
set.seed(42)

pres_m_post <-extract.samples(pres_m, n=10000)
pres_m_post_prob <- length(pres_m_post[which(pres_m_post$aGeneral>SoPDBdf$pres)])/length(pres_m_post$aG
cat("Calculated posterior probability: ",  pres_m_post_prob)
```

Posterior Probability that the hypothesis "This Sense of Presence subscale scored higher than the IGroup norm provided" holds.

```
## Calculated posterior probability:  0.9959
```

```
round(HPDI(pres_m_post$aGeneral, prob = 0.95), 2)
```

```
## |0.95 0.95|
##  3.67  4.82
```

Spatial Presence

```
set.seed(42)

sp_m <- ulam(
  alist(
```

```
    SP_Score ~ dstudent(v, mu, sigma),
    v ~ gamma(2,0.1),
    mu <- aGeneral,
    aGeneral ~ dnorm(3, 10),
    sigma ~ dexp(1)
  ), data = SoPdf, iter = 10000, chains = 4, cores = 4
)
```

```
precis(sp_m, prob = 0.95)
```

```
##               mean        sd      2.5%    97.5%    n_eff     Rhat4
## v        2.1261095 0.4397628 1.3510715 3.079484 17217.21 0.9999884
## aGeneral 3.8934645 0.2514035 3.3738137 4.363798 15681.83 0.9998846
## sigma    0.8245385 0.2133565 0.4837905 1.309687 14981.22 0.9998708
```

```
set.seed(42)

sp_m_post <-extract.samples(sp_m, n=10000)
sp_m_post_prob <- length(sp_m_post[which(sp_m_post$aGeneral>SoPDBdf$sp)])/length(sp_m_post$aGeneral)
cat("Calculated posterior probability: ",  sp_m_post_prob)
```

Posterior Probability that the hypothesis "This Sense of Presence subscale scored higher than the IGroup norm provided" holds.

```
## Calculated posterior probability:  0.729
```

```
round(HPDI(sp_m_post$aGeneral, prob = 0.95), 2)
```

```
## |0.95 0.95|
##  3.40  4.38
```

Involvement

```
set.seed(42)

inv_m <- ulam(
  alist(
    INV_Score ~ dstudent(v, mu, sigma),
    v ~ gamma(2,0.1),
    mu <- aGeneral,
    aGeneral ~ dnorm(3, 10),
    sigma ~ dexp(1)
  ), data = SoPdf, iter = 10000, chains = 4, cores = 4
)
```

```
precis(inv_m, prob = 0.95)
```

```
##               mean        sd      2.5%    97.5%    n_eff     Rhat4
## v        2.1937832 0.4495761 1.4080000 3.161580 17485.91 1.0000113
## aGeneral 3.4260970 0.3027625 2.8322150 4.019669 17874.69 0.9999383
## sigma    0.9771716 0.2352430 0.5985635 1.521083 15162.54 0.9999407
```

```
set.seed(42)
```

```
inv_m_post <-extract.samples(inv_m, n=10000)
inv_m_post_prob <- length(inv_m_post[which(inv_m_post$aGeneral>SoPDBdf$inv)])/length(inv_m_post$aGeneral
cat("Calculated posterior probability: ",  inv_m_post_prob)
```

Posterior Probability that the hypothesis "This Sense of Presence subscale scored higher than the IGroup norm provided" holds.

```
## Calculated posterior probability:  0.9249
```

```
round(HPDI(inv_m_post$aGeneral, prob = 0.95), 2)
```

```
## |0.95 0.95|
##  2.81  3.99
```

Experienced Realism

```
set.seed(42)

real_m <- ulam(
  alist(
    REAL_Score ~ dstudent(v, mu, sigma),
    v ~ gamma(2,0.1),
    mu <- aGeneral,
    aGeneral ~ dnorm(3, 10),
    sigma ~ dexp(1)
  ), data = SoPdf, iter = 10000, chains = 4, cores = 4
)
```

```
precis(real_m, prob = 0.95)
```

```
##                mean        sd      2.5%    97.5%    n_eff    Rhat4
## v         2.0779784 0.4381793 1.3101663 3.032917 16587.31 1.000249
## aGeneral 2.7398988 0.2048501 2.3600258 3.169715 14740.25 1.000137
## sigma     0.6841963 0.1874721 0.3823509 1.108741 15384.21 1.000204
```

```
set.seed(42)

real_m_post <-extract.samples(real_m, n=10000)
real_m_post_prob <- length(real_m_post[which(real_m_post$aGeneral>SoPDBdf$real)])/length(real_m_post$aG
cat("Calculated posterior probability: ",  real_m_post_prob)
```

Posterior Probability that the hypothesis "This Sense of Presence subscale scored higher than the IGroup norm provided" holds.

```
## Calculated posterior probability:  0.9999
```

```
round(HPDI(real_m_post$aGeneral, prob = 0.95), 2)
```

```
## |0.95 0.95|
##  2.34  3.14
```

Component-Based Usability Questionnaire

Results here are reported in Table 4.4 of Section 4.2.2 in the thesis report.

Loading Data

```
cbuq_df = read.csv("Data/cbuq_data.csv")
```

Adjusting Column

```
cbuq_df$subjectF <- factor(cbuq_df$X, levels = c(0:19), labels = c(0:19))
```

```
set.seed(42)

cbuq_m <- ulam(
  alist(
    mean_score ~ dstudent(v, mu, sigma),
    v ~ gamma(2,0.1),
    mu <- aGeneral,
    aGeneral ~ dnorm(4, 10),
    sigma ~ dexp(1)
  ), data = cbuq_df, iter = 10000, chains = 4, cores = 4
)
```

```
precis(cbuq_m, prob = 0.95)
```

```
##               mean        sd      2.5%    97.5%   n_eff     Rhat4
## v        2.0120976 0.4216895 1.2840928 2.923893 16210.8 1.0001351
## aGeneral 6.2175027 0.2053570 5.7935112 6.607977 14372.0 1.0002716
## sigma    0.6879577 0.1920087 0.3890169 1.136467 14135.7 0.9999291
```

```
set.seed(42)

cbuq_m_post <-extract.samples(cbuq_m, n=10000)
cbuq_m_post_prob <- length(cbuq_m_post[which(cbuq_m_post$aGeneral>5.29)])/length(cbuq_m_post$aGeneral)
cat("Calculated posterior probability: ",  cbuq_m_post_prob)
```

```
## Calculated posterior probability:  1
```

```
round(HPDI(cbuq_m_post$aGeneral, prob = 0.95), 2)
```

```
## |0.95 0.95|
##  5.81  6.61
```

Additional Usability Questions

Results here are reported in Table 4.4 of Section 4.2.2 in the thesis report.

Loading Data

```
auq_df = read.csv("Data/auq_scores_data.csv")
```

Adjusting Column

```
auq_df$subjectF <- factor(auq_df$X, levels = c(0:19), labels = c(0:19))
```

Question 1: "How easy or difficult was it to read the text displayed on the virtual smartphone screen?" [-5,5] (Very difficult, Neutral, Very easy)

```
set.seed(42)

auq_q1_m <- ulam(
  alist(
    Q1 ~ dstudent(v, mu, sigma),
    v ~ gamma(2,0.1),
    mu <- aGeneral,
    aGeneral ~ dnorm(0, 10),
    sigma ~ dexp(1)
  ), data = auq_df, iter = 10000, chains = 4, cores = 4
)
```

```
precis(auq_q1_m, prob = 0.95)
```

```
##              mean        sd      2.5%    97.5%    n_eff    Rhat4
## v        1.968155 0.4398090 1.2200182 2.925249 13196.42 1.000092
## aGeneral 3.039658 0.3782011 2.1928221 3.705107 10646.08 1.000171
## sigma    1.207220 0.3735259 0.6229883 2.071443 11399.91 1.000236
```

```
set.seed(42)

auq_q1_m_post <-extract.samples(auq_q1_m, n=10000)
auq_q1_m_post_prob <- length(auq_q1_m_post[which(auq_q1_m_post$aGeneral>0)])/length(auq_q1_m_post$aGene
cat("Calculated posterior probability: ",  auq_q1_m_post_prob)
```

```
## Calculated posterior probability:  1
```

```
round(HPDI(auq_q1_m_post$aGeneral, prob = 0.95), 2)
```

```
## |0.95 0.95|
##  2.23  3.71
```

Question 2: "The size of the virtual smartphone was." [-5,5] (Too big, Just right, Too small) -> Modified in pre-processing to [0,5] corresponding to (Not appropriate, Appropriate).

```
set.seed(42)

auq_q2_m <- ulam(
  alist(
    Q2 ~ dstudent(v, mu, sigma),
    v ~ gamma(2,0.1),
    mu <- aGeneral,
    aGeneral ~ dnorm(3.5, 10),
    sigma ~ dexp(1)
  ), data = auq_df, iter = 10000, chains = 4, cores = 4
)
```

```
precis(auq_q2_m, prob = 0.95)
```

```
##                  mean           sd         2.5%        97.5%        n_eff    Rhat4
## v        4.061697e-01 6.218131e-02 2.788303e-01 4.669648e-01     2.077425 7.080056
## aGeneral 5.000000e+00 2.030327e-07 5.000000e+00 5.000000e+00 19357.009570 1.000224
```

```
## sigma    1.128157e-06 4.476766e-07 5.495728e-07 1.953186e-06     3.029288 2.410521
```

```
set.seed(42)

auq_q2_m_post <-extract.samples(auq_q2_m, n=10000)
auq_q2_m_post_prob <- length(auq_q2_m_post[which(auq_q2_m_post$aGeneral>3.5)])/length(auq_q2_m_post$aGe
cat("Calculated posterior probability: ",  auq_q2_m_post_prob)
```

```
## Calculated posterior probability:  1
```

```
round(HPDI(auq_q2_m_post$aGeneral, prob = 0.95), 2)
```

```
## |0.95 0.95|
##     5     5
```

Question 3: "The location of the virtual smartphone in your field of view was." [-5,5] (Very inappropriate, Neutral, Very appropriate)

```
set.seed(42)

auq_q3_m <- ulam(
  alist(
    Q3 ~ dstudent(v, mu, sigma),
    v ~ gamma(2,0.1),
    mu <- aGeneral,
    aGeneral ~ dnorm(0, 10),
    sigma ~ dexp(1)
  ), data = auq_df, iter = 10000, chains = 4, cores = 4
)
```

```
precis(auq_q3_m, prob=.95 )
```

```
##              mean        sd     2.5%    97.5%    n_eff   Rhat4
## v        2.160768 0.4513205 1.375427 3.144425 17105.81 0.99990
## aGeneral 2.903661 0.5357926 1.800799 3.880886 13957.87 1.00004
## sigma    1.631740 0.3991508 0.981033 2.531659 15265.66 1.00001
```

```
set.seed(42)

auq_q3_m_post <-extract.samples(auq_q3_m, n=10000)
auq_q3_m_post_prob <- length(auq_q3_m_post[which(auq_q3_m_post$aGeneral>0)])/length(auq_q3_m_post$aGene
cat("Calculated posterior probability: ",  auq_q3_m_post_prob)
```

```
## Calculated posterior probability:  1
```

```
round(HPDI(auq_q3_m_post$aGeneral, prob = 0.95), 2)
```

```
## |0.95 0.95|
##  1.85  3.91
```

Question 4: "The orientation (rotation / tilt) of the virtual smartphone was." [-5,5] (Very inappropriate, Neutral, Very appropriate)

```
set.seed(42)

auq_q4_m <- ulam(
```

```
  alist(
    Q4 ~ dstudent(v, mu, sigma),
    v ~ gamma(2,0.1),
    mu <- aGeneral,
    aGeneral ~ dnorm(0, 10),
    sigma ~ dexp(1)
  ), data = auq_df, iter = 10000, chains = 4, cores = 4
)
```

```
precis(auq_q4_m, prob=.95 )
```

```
##              mean        sd      2.5%    97.5%    n_eff     Rhat4
## v        2.123650 0.4510796 1.3333704 3.088709 14759.31 0.9999998
## aGeneral 2.518611 0.4930605 1.4559561 3.396141 12665.86 1.0001686
## sigma    1.518402 0.4014537 0.8506389 2.421833 12966.27 1.0001563
```

```
set.seed(42)

auq_q4_m_post <-extract.samples(auq_q4_m, n=10000)
auq_q4_m_post_prob <- length(auq_q4_m_post[which(auq_q4_m_post$aGeneral>0)])/length(auq_q4_m_post$aGene
cat("Calculated posterior probability: ",  auq_q4_m_post_prob)
```

```
## Calculated posterior probability:  0.9999
```

```
round(HPDI(auq_q4_m_post$aGeneral, prob = 0.95), 2)
```

```
## |0.95 0.95|
##  1.55  3.46
```

Question 5: "The notification sound and the virtual smartphone appearing was." [-5,5] (Very disturbing, Neutral, Very intuitive)

```
set.seed(42)

auq_q5_m <- ulam(
  alist(
    Q5 ~ dstudent(v, mu, sigma),
    v ~ gamma(2,0.1),
    mu <- aGeneral,
    aGeneral ~ dnorm(0, 10),
    sigma ~ dexp(1)
  ), data = auq_df, iter = 10000, chains = 4, cores = 4
)
```

```
precis(auq_q5_m, prob=.95 )
```

```
##              mean        sd      2.5%    97.5%    n_eff     Rhat4
## v        2.085842 0.4381796 1.3303386 3.033832 16744.12 1.0000331
## aGeneral 2.546053 0.4548101 1.5829583 3.378777 14584.98 1.0005081
## sigma    1.465800 0.3816181 0.8534114 2.350452 14387.55 0.9999901
```

```
set.seed(42)

auq_q5_m_post <-extract.samples(auq_q5_m, n=10000)
auq_q5_m_post_prob <- length(auq_q5_m_post[which(auq_q5_m_post$aGeneral>0)])/length(auq_q5_m_post$aGene
cat("Calculated posterior probability: ",  auq_q5_m_post_prob)
```

```
## Calculated posterior probability:  1
```

```
round(HPDI(auq_q5_m_post$aGeneral, prob = 0.95), 2)
```

```
## |0.95 0.95|
##  1.64  3.44
```

Question 6: "I would prefer the virtual smartphone to: A. Move with me when I look around in the virtual environments and remain stable at the same position in my field of view. B. Not move with me when I look around in the virtual environment and remain stable at the same location in the environment." [-5, 5] (Completely prefer A, Neutral, Completely prefer B). Scale reversed in pre-processing so that A, which is the option we offered, is considered the positive value.

```
set.seed(42)

auq_q6_m <- ulam(
  alist(
    Q6 ~ dstudent(v, mu, sigma),
    v ~ gamma(2,0.1),
    mu <- aGeneral,
    aGeneral ~ dnorm(0, 10),
    sigma ~ dexp(1)
  ), data = auq_df, iter = 10000, chains = 4, cores = 4
)
```

```
precis(auq_q6_m, prob=.95 )
```

```
##              mean        sd     2.5%    97.5%    n_eff     Rhat4
## v        2.048268 0.4459502 1.276830 3.021833 12524.23 0.9999228
## aGeneral 2.802658 0.7005480 1.251896 4.022122 11639.74 0.9998631
## sigma    2.109946 0.5905410 1.150094 3.438708 11003.63 1.0001521
```

```
set.seed(42)

auq_q6_m_post <-extract.samples(auq_q6_m, n=10000)
auq_q6_m_post_prob <- length(auq_q6_m_post[which(auq_q6_m_post$aGeneral>0)])/length(auq_q6_m_post$aGene
cat("Calculated posterior probability: ",  auq_q6_m_post_prob)
```

```
## Calculated posterior probability:  0.999
```

```
round(HPDI(auq_q6_m_post$aGeneral, prob = 0.95), 2)
```

```
## |0.95 0.95|
##  1.39  4.13
```

Question 7: "I found the viewing duration of virtual environments to be." [-5,5] (Too short, Just right, Too long) -> Modified in pre-processing to [0,5] corresponding to (Not appropriate, Appropriate).

```
set.seed(42)

auq_q7_m <- ulam(
  alist(
```

```
    Q7 ~ dstudent(v, mu, sigma),
    v ~ gamma(2,0.1),
    mu <- aGeneral,
    aGeneral ~ dnorm(3.5, 10),
    sigma ~ dexp(1)
  ), data = auq_df, iter = 10000, chains = 4, cores = 4
)
```

```
precis(auq_q7_m, prob=.95 )
```

```
##              mean        sd      2.5%    97.5%    n_eff     Rhat4
## v        2.208042 0.4526031 1.4222644 3.186175 18607.53 0.9999765
## aGeneral 2.332390 0.3906897 1.5419722 3.075577 16514.65 1.0001010
## sigma    1.230384 0.2898381 0.7592474 1.881647 16714.36 1.0000771
```

```
set.seed(42)

auq_q7_m_post <-extract.samples(auq_q7_m, n=10000)
auq_q7_m_post_prob <- length(auq_q7_m_post[which(auq_q7_m_post$aGeneral>3.5)])/length(auq_q7_m_post$aGe
cat("Calculated posterior probability: ",  auq_q7_m_post_prob)
```

```
## Calculated posterior probability:  0.0012
```

```
round(HPDI(auq_q7_m_post$aGeneral, prob = 0.95), 2)
```

```
## |0.95 0.95|
##  1.59  3.09
```

Ease of Material Collection Question: "I found the preparation of material (photos / video / audio) I was asked to submit." [-5, 5] (Very difficult, Neutral, Very easy)

```
set.seed(42)

eomc_m <- ulam(
  alist(
    Q8 ~ dstudent(v, mu, sigma),
    v ~ gamma(2,0.1),
    mu <- aGeneral,
    aGeneral ~ dnorm(0, 10),
    sigma ~ dexp(1)
  ), data = auq_df, iter = 10000, chains = 4, cores = 4
)
```

```
precis(eomc_m, prob=.95 )
```

```
##               mean        sd       2.5%    97.5%    n_eff     Rhat4
## v        2.1540493 0.4475017  1.3815591 3.113640 16198.77 0.9999251
## aGeneral 0.2054679 0.6108456 -0.9705473 1.449682 16298.00 0.9999200
## sigma    1.9437994 0.4690960  1.1660896 2.999478 14804.63 0.9999441
```

```
set.seed(42)

eomc_m_post <-extract.samples(eomc_m, n=10000)
eomc_m_post_prob <- length(eomc_m_post[which(eomc_m_post$aGeneral>0)])/length(eomc_m_post$aGeneral)
cat("Calculated posterior probability: ",  eomc_m_post_prob)
```

```
## Calculated posterior probability:  0.6333
```

```
round(HPDI(eomc_m_post$aGeneral, prob = 0.95), 2)
```

```
## |0.95 0.95|
## -0.99  1.47
```