Los Alamos
NATIONAL LABORATORY
EST.1943

LA-UR-15-25714
Approved for public release; distribution is unlimited.

Title: Analyzing Task-Based User Study Data to Determine Colormap Efficiency

Author(s): Ashton, Zoe Charon Maria
Wendelberger, Joanne Roth
Ticknor, Lawrence O.
Turton, Terece
Samsel, Francesca

Intended for: Technical Exchange with Colleagues
Report

Issued: 2015-07-23

**Disclaimer:**
Los Alamos National Laboratory, an affirmative action/equal opportunity employer,is operated by the Los Alamos National Security, LLC for the National NuclearSecurity Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. By approving this article, the publisher recognizes that the U.S. Government retains nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Departmentof Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

# Analyzing Task-Based User Study Data to Determine Colormap Efficiency

Zoe Ashton[1,2], Joanne Wendelberger[2], Lawrence Ticknor[2],

Terece Turton[3], Francesca Samsel[3]

1: Florida Institute of Technology

2: Statistical Science Group, Los Alamos National Laboratory

3: Center for Agile Technology, University of Texas

UNCLASSIFIED

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

# Introduction

- Domain scientists use colormaps to visualize their data.
- Useful for identifying areas of interest.
  - Eddy Identification
  - Characterizing Currents
- New colormaps have been designed by visual artist Francesca Samsel.
- User studies implemented to determine whether or not these colormaps are an improvement.

# Background on User Study

- Set up using Qualtrics software.



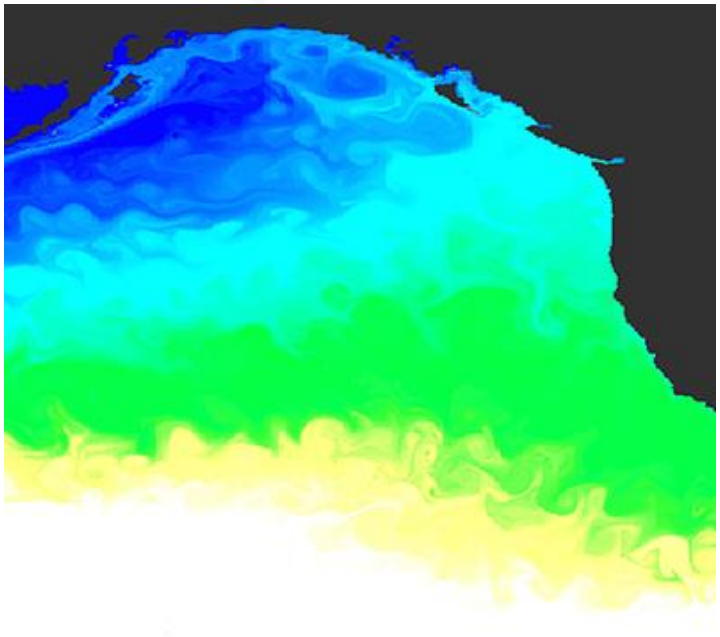
Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

# Background on User Study

- Set up using Qualtrics software.
- Distributed to participants via email solicitation and the University of Texas Psychology PSY301 Subject Pool.

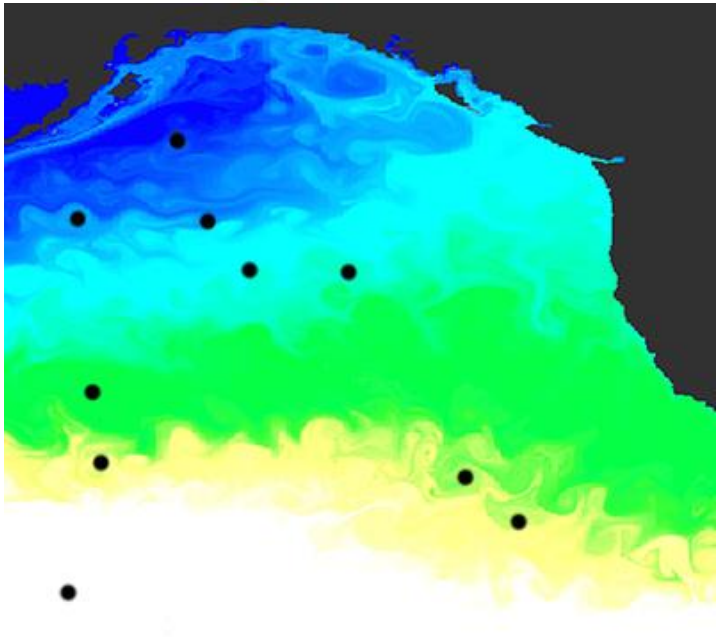
# Background on User Study

- Set up using Qualtrics software.
- Distributed to participants via email solicitation and the University of Texas Psychology PSY301 Subject Pool.
- Users were asked to click on each distinct color they saw in the picture.



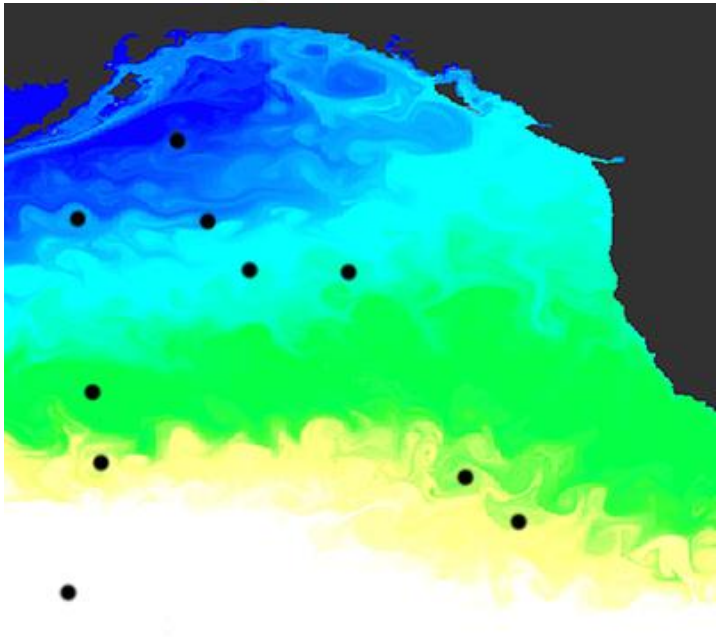
# Background on User Study

- Set up using Qualtrics software.
- Distributed to participants via email solicitation and the University of Texas Psychology PSY301 Subject Pool.
- Users were asked to click on each distinct color they saw in the picture.



# Background on User Study

- Set up using Qualtrics software.
- Distributed to participants via email solicitation and the University of Texas Psychology PSY301 Subject Pool.
- Users were asked to click on each distinct color they saw in the picture.
- They were also asked to provide their age, gender, and level of education.



# Colormaps Tested

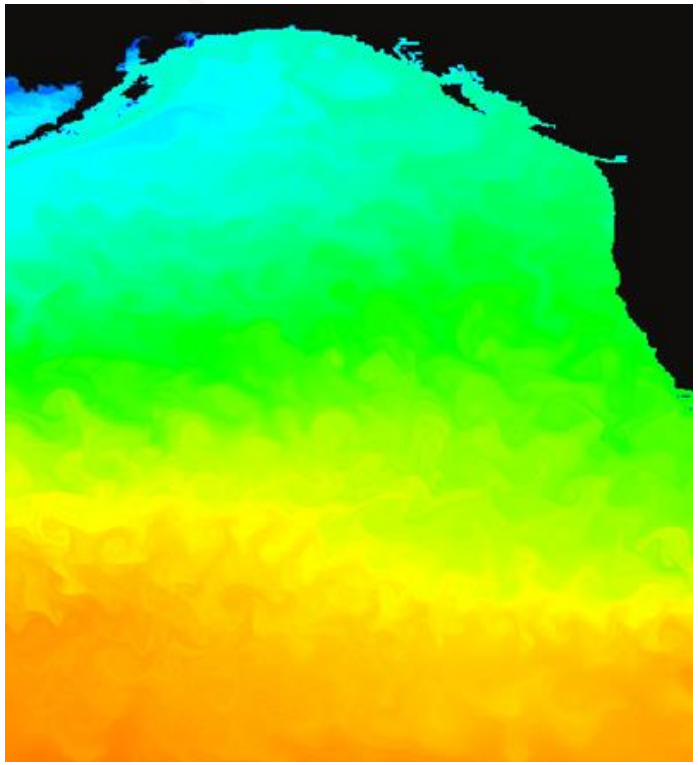
- Eight different colormaps were tested.

# Colormaps Tested

- Eight different colormaps were tested.
- Three were traditional.

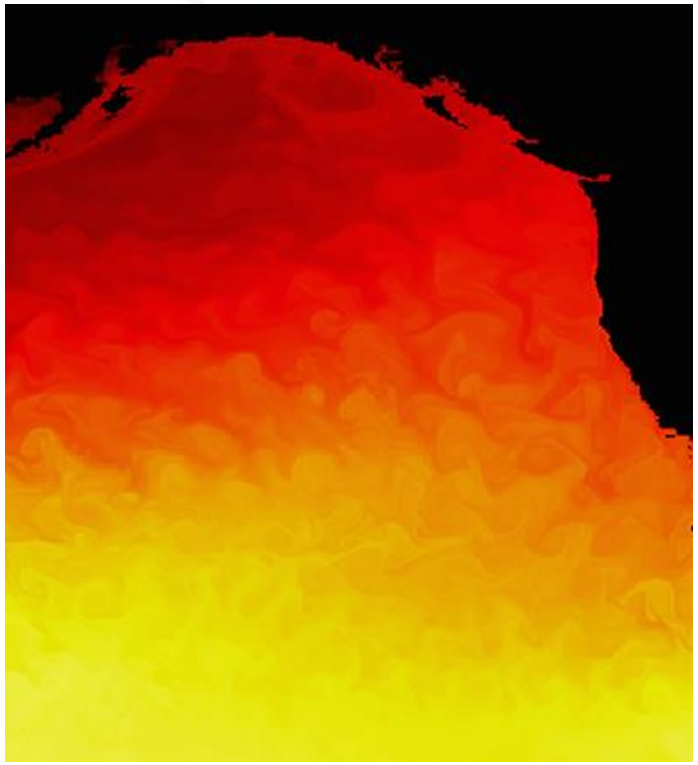
# Colormaps Tested

- Eight different colormaps were tested.
- Three were traditional.
  - Rainbow



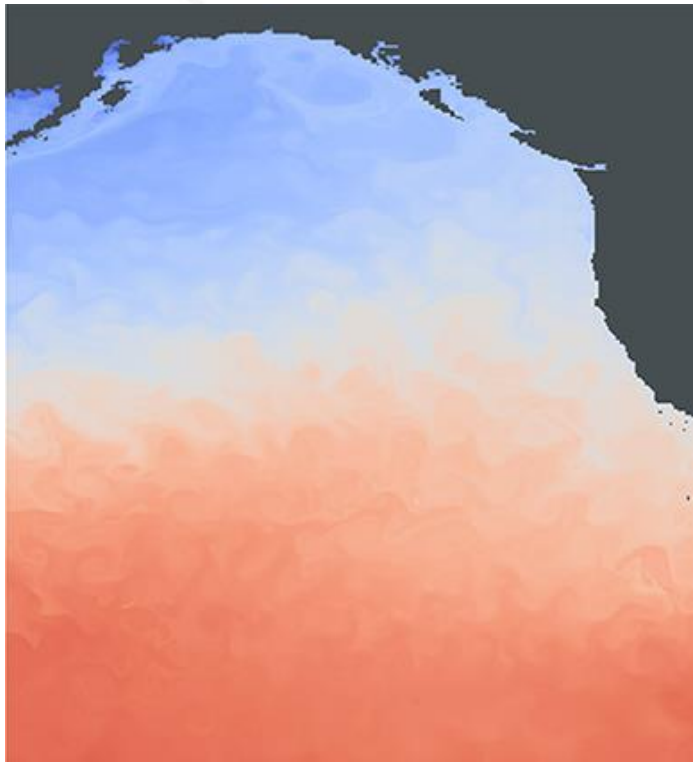
# Colormaps Tested

- Eight different colormaps were tested.
- Three were traditional.
  - Rainbow
  - Heat Map



# Colormaps Tested

- Eight different colormaps were tested.
- Three were traditional.
  - Rainbow
  - Heat Map
  - Cool/Warm



# Colormaps Tested

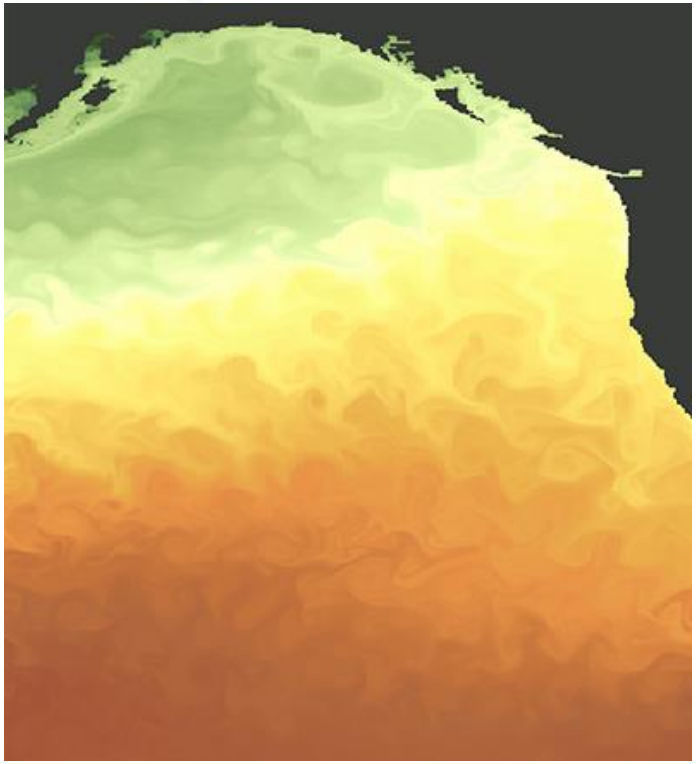
- Eight different colormaps were tested.
- Three were traditional.
- Four colormaps were designed using perceptual theory concepts, with the goal of being more effective.

# Colormaps Tested

- Eight different colormaps were tested.
- Three were traditional.
- Four colormaps were designed using perceptual theory concepts, with the goal of being more effective.
  - Gold/Grey

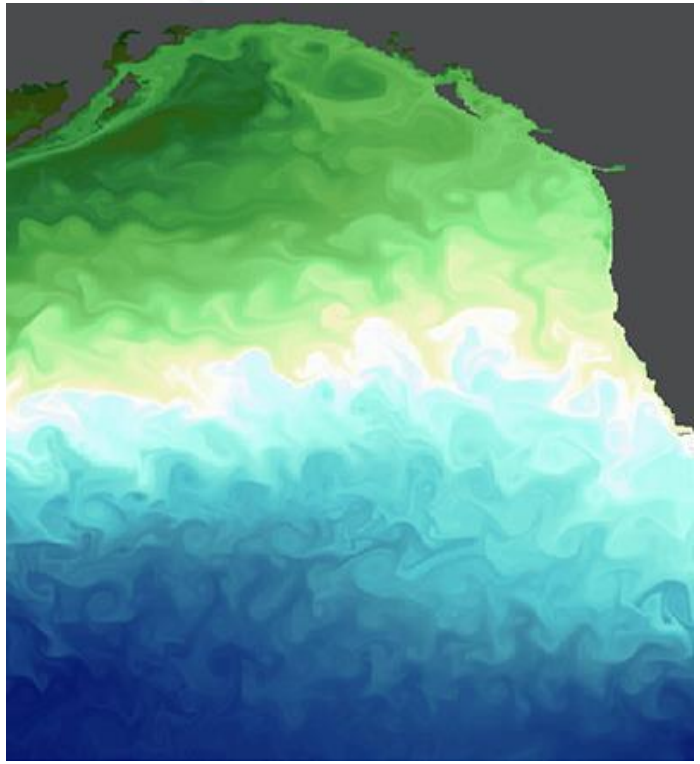
# Colormaps Tested

- Eight different colormaps were tested.
- Three were traditional.
- Four colormaps were designed using perceptual theory concepts, with the goal of being more effective.
  - Gold/Grey
  - Autumn



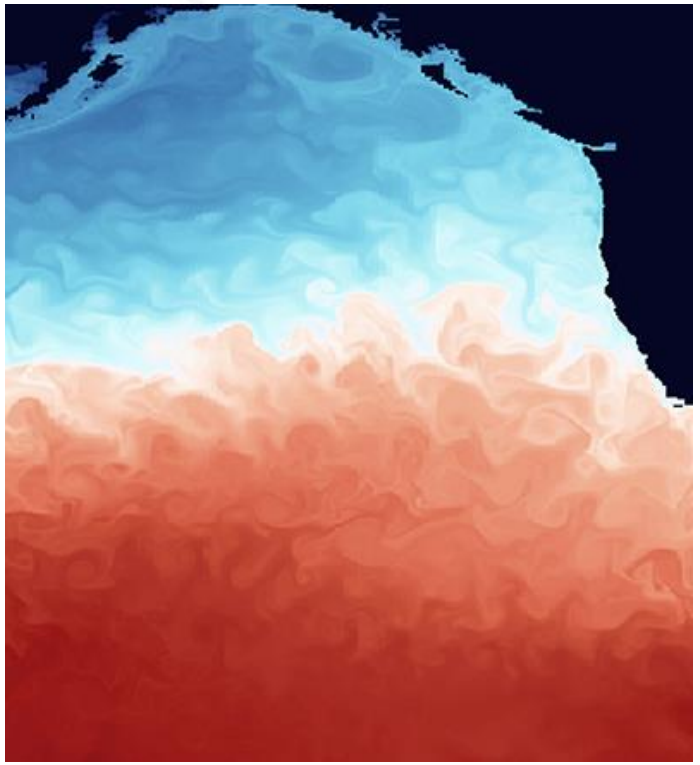
# Colormaps Tested

- Eight different colormaps were tested.
- Three were traditional.
- Four colormaps were designed using perceptual theory concepts, with the goal of being more effective.
  - Gold/Grey
  - Autumn
  - Blue/Green Asymmetric Divergent



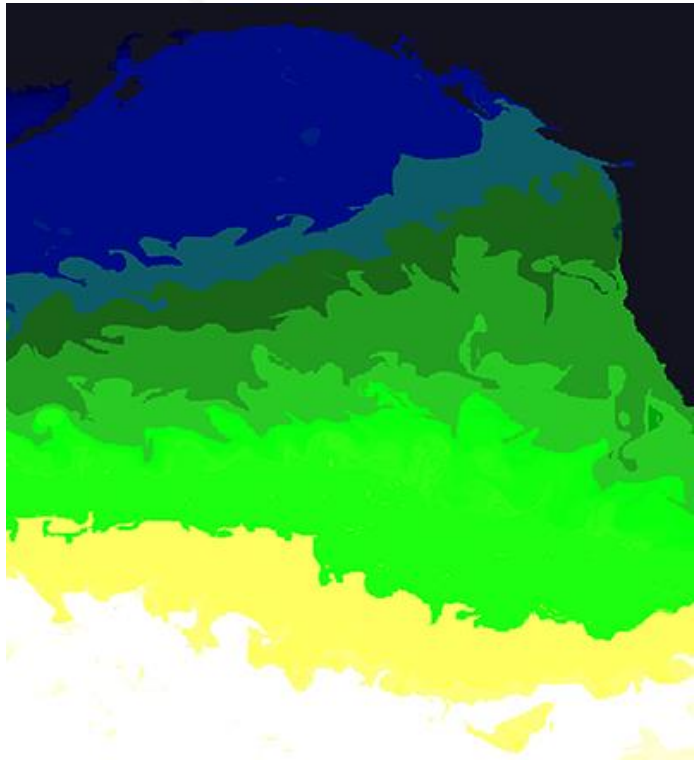
# Colormaps Tested

- Eight different colormaps were tested.
- Three were traditional.
- Four colormaps were designed using perceptual theory concepts, with the goal of being more effective.
  - Gold/Grey
  - Autumn
  - Blue/Green Asymmetric Divergent
  - Extended Cool/Warm



# Colormaps Tested

- Eight different colormaps were tested.
- Three were traditional.
- Four colormaps were designed using perceptual theory concepts, with the goal of being more effective.
- One was a validation panel.



# Validating the Data

- Original number of responses was 77.



NNSA National Nuclear Security Administration

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

Los Alamos NATIONAL LABORATORY EST. 1943

# Validating the Data

- Original number of responses was 77.
- Responses not within +/- 2 colors of the validation panel were discarded.

# Validating the Data

- Original number of responses was 77.
- Responses not within +/- 2 colors of the validation panel were discarded.
- Valid number of responses was 63.

# Understanding the Data

- Each of the responses includes a count of perceived colors for each colormap and values for education, age, and gender.

# Understanding the Data

- Each of the responses includes a count of perceived colors for each colormap and values for education, age, and gender.
- Education
  - 1: Some High School
  - 2: High School Diploma or GED
  - 3: Some College of Associate Degree
  - 4: Undergraduate Degree
  - 5: Masters Degree
  - 6: Doctorate or Professional Degree
  - 7: Other (Please Explain)
  - 8: Prefer Not to Respond

# Understanding the Data

- Each of the responses includes a count of perceived colors for each colormap and values for education, age, and gender.
- Education
- Age
  - 1: 18-25
  - 2: 26-30
  - 3: 31-40
  - 4: 41-50
  - 5: 51-60
  - 6: 61-70
  - 7: 71+

# Understanding the Data

- Each of the responses includes a count of perceived colors for each colormap and values for education, age, and gender.
- Education
- Age
- Gender
  - 1: Male
  - 2: Female
  - 3: Other/Prefer not to respond

# How Many Perceivable Colors?

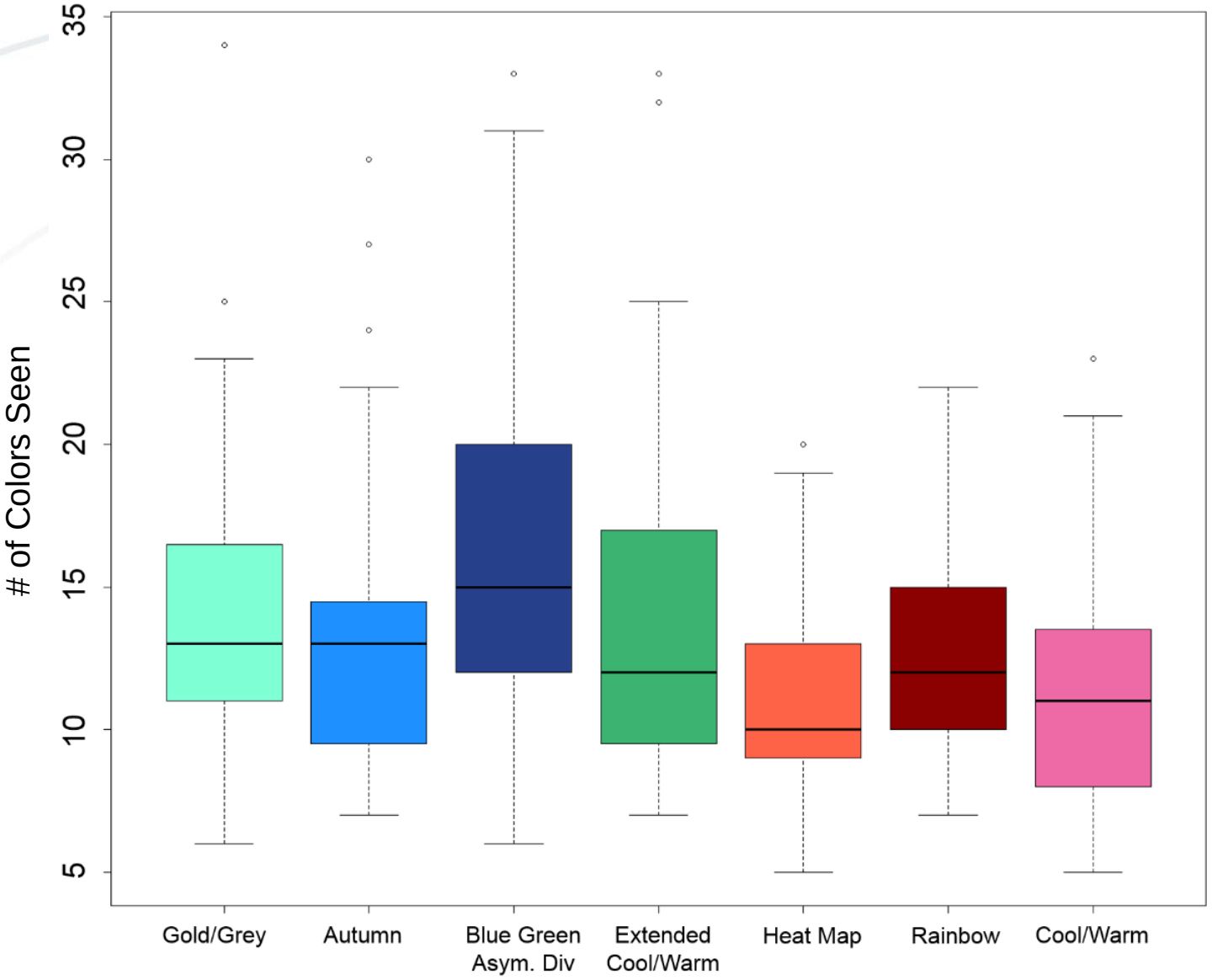
- The main concern is whether or not the colormap affects the number of perceivable colors.

# How Many Perceivable Colors?

- The main concern is whether or not the colormap affects the number of perceivable colors.
- Start by looking at the distributions of the data and comparing the colormaps to each other.

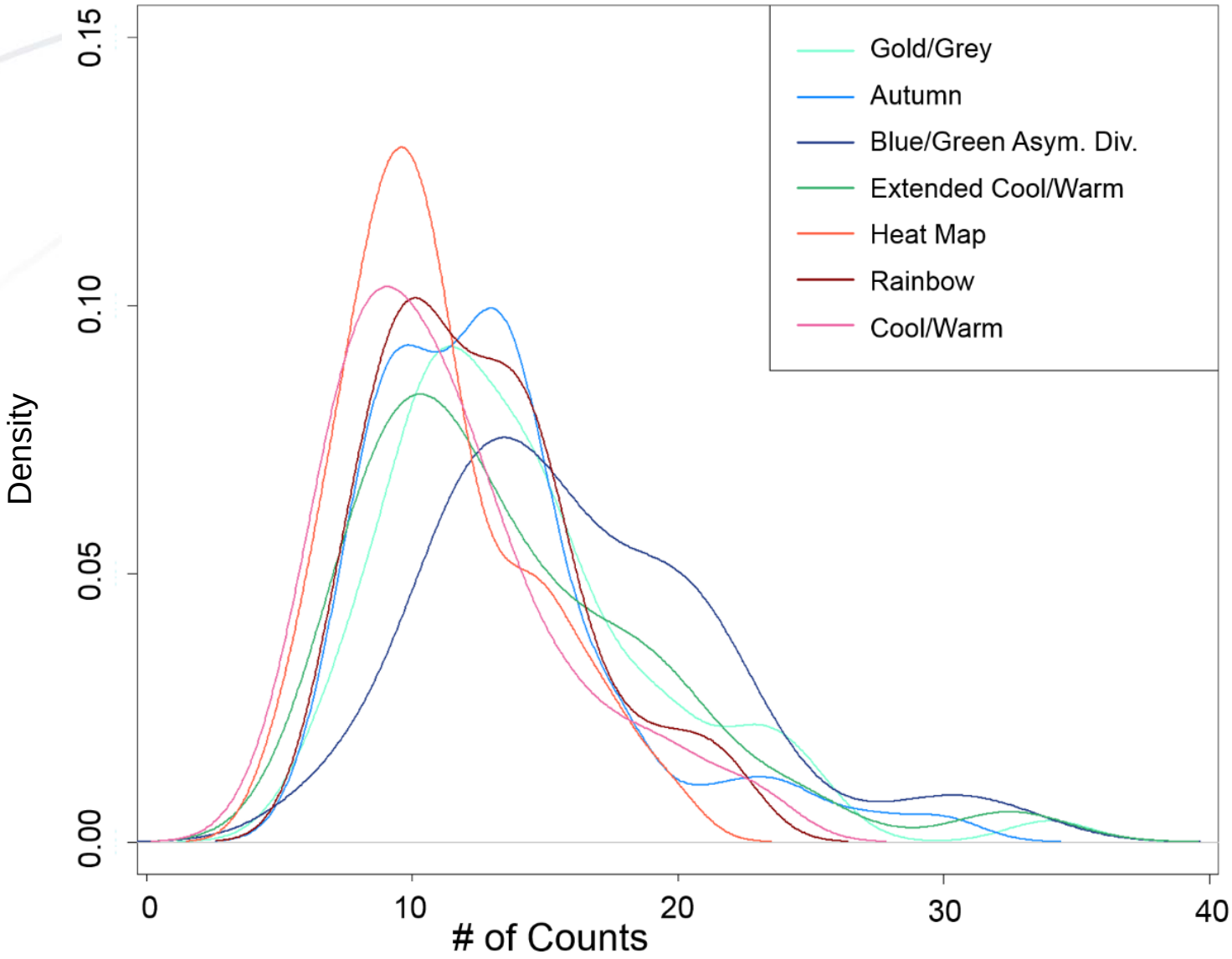
# How Many Perceivable Colors?

- The main concern is whether or not the colormap affects the number of perceivable colors.
- Start by looking at the distributions of the data and comparing the colormaps to each other.
- Then compare the colormap counts using statistical tests.




UNCLASSIFIED

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA




UNCLASSIFIED

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

# Are the Counts for New Colormaps Higher?

- Used a one-tailed sign test to compare the counts of each colormap.

# Are the Counts for New Colormaps Higher?

- Used a one-tailed sign test to compare the counts of each colormap.
- $H_0$: Colormap X's counts are the same or lower than Y's.



NNSA National Nuclear Security Administration
Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA
Los Alamos NATIONAL LABORATORY EST. 1943

# Are the Counts for New Colormaps Higher?

- Used a one-tailed sign test to compare the counts of each colormap.
- $H_0$: Colormap X's counts are the same or lower than Y's.
- $H_1$: Colormap X's counts are higher than Colormap Y's Counts



NNSA National Nuclear Security Administration
Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA
Los Alamos NATIONAL LABORATORY EST. 1943

# Are the Counts for New Colormaps Higher?

- Used a one-tailed sign test to compare the counts of each colormap.
- $H_0$: Colormap X's counts are the same or lower than Y's.
- $H_1$: Colormap X's counts are higher than Colormap Y's Counts

| | Cool/Warm | Rainbow | Heat Map | Extended Cool/Warm | Autumn | Gold/Grey |
|---|---|---|---|---|---|---|
| **Blue/Green Asym. Div.** | 1.59E-12 | 6.80E-10 | 8.21E-16 | 3.78E-07 | 8.37E-08 | 2.61E-05 |
| **Gold/Grey** | 1.63E-09 | 6.38E-05 | 4.53E-09 | 0.110 | 9.92E-03 | |
| **Autumn** | 2.05E-04 | 0.292 | 3.67E-05 | 0.965 | | |
| **Extended Cool/Warm** | 1.02E-06 | 0.248 | 1.36E-08 | | | |
| **Heat Map** | 0.920 | 1.00 | | | | |
| **Rainbow** | 7.69E-05 | | | | | |

# Are the Counts for New Colormaps Higher?

| | Cool/Warm | Rainbow | Heat Map | Extended Cool/Warm | Autumn | Gold/Grey |
|---|---|---|---|---|---|---|
| **Blue/Green Asym. Div.** | 1.59E-12 | 6.80E-10 | 8.21E-16 | 3.78E-07 | 8.37E-08 | 2.61E-05 |
| **Gold/Grey** | 1.63E-09 | 6.38E-05 | 4.53E-09 | 0.110 | 9.92E-03 | |
| **Autumn** | 2.05E-04 | 0.292 | 3.67E-05 | 0.965 | | |
| **Extended Cool/Warm** | 1.02E-06 | 0.248 | 1.36E-08 | | | |
| **Heat Map** | 0.920 | 1.00 | | | | |
| **Rainbow** | 7.69E-05 | | | | | |

# Are the Counts for New Colormaps Higher?

| | Cool/Warm | Rainbow | Heat Map | Extended Cool/Warm | Autumn | Gold/Grey |
|---|---|---|---|---|---|---|
| **Blue/Green Asym. Div.** | 1.59E-12 | 6.80E-10 | 8.21E-16 | 3.78E-07 | 8.37E-08 | 2.61E-05 |
| **Gold/Grey** | 1.63E-09 | 6.38E-05 | 4.53E-09 | 0.110 | 9.92E-03 | |
| **Autumn** | 2.05E-04 | 0.292 | 3.67E-05 | 0.965 | | |
| **Extended Cool/Warm** | 1.02E-06 | 0.248 | 1.36E-08 | | | |
| **Heat Map** | 0.920 | 1.00 | | | | |
| **Rainbow** | 7.69E-05 | | | | | |

# Are the Counts for New Colormaps Higher?

| | Cool/Warm | Rainbow | Heat Map | Extended Cool/Warm | Autumn | Gold/Grey |
|---|---|---|---|---|---|---|
| **Blue/Green Asym. Div.** | 1.59E-12 | 6.80E-10 | 8.21E-16 | 3.78E-07 | 8.37E-08 | 2.61E-05 |
| **Gold/Grey** | 1.63E-09 | 6.38E-05 | 4.53E-09 | 0.110 | 9.92E-03 | |
| **Autumn** | 2.05E-04 | 0.292 | 3.67E-05 | 0.965 | | |
| **Extended Cool/Warm** | 1.02E-06 | 0.248 | 1.36E-08 | | | |
| **Heat Map** | 0.920 | 1.00 | | | | |
| **Rainbow** | 7.69E-05 | | | | | |

# Are the Counts for New Colormaps Higher?

| | Cool/Warm | Rainbow | Heat Map | Extended Cool/Warm | Autumn | Gold/Grey |
|---|---|---|---|---|---|---|
| **Blue/Green Asym. Div.** | 1.59E-12 | 6.80E-10 | 8.21E-16 | 3.78E-07 | 8.37E-08 | 2.61E-05 |
| **Gold/Grey** | 1.63E-09 | 6.38E-05 | 4.53E-09 | 0.110 | 9.92E-03 | |
| **Autumn** | 2.05E-04 | 0.292 | 3.67E-05 | 0.965 | | |
| **Extended Cool/Warm** | 1.02E-06 | 0.248 | 1.36E-08 | | | |
| **Heat Map** | 0.920 | 1.00 | | | | |
| **Rainbow** | 7.69E-05 | | | | | |

# Are the Counts for New Colormaps Higher?

| | Cool/Warm | Rainbow | Heat Map | Extended Cool/Warm | Autumn | Gold/Grey |
|---|---|---|---|---|---|---|
| **Blue/Green Asym. Div.** | 1.59E-12 | 6.80E-10 | 8.21E-16 | 3.78E-07 | 8.37E-08 | 2.61E-05 |
| **Gold/Grey** | 1.63E-09 | 6.38E-05 | 4.53E-09 | 0.110 | 9.92E-03 | |
| **Autumn** | 2.05E-04 | 0.292 | 3.67E-05 | 0.965 | | |
| **Extended Cool/Warm** | 1.02E-06 | 0.248 | 1.36E-08 | | | |
| **Heat Map** | 0.920 | 1.00 | | | | |
| **Rainbow** | 7.69E-05 | | | | | |

# Are the Counts for New Colormaps Higher?

| | Cool/Warm | Rainbow | Heat Map | Extended Cool/Warm | Autumn | Gold/Grey |
|---|---|---|---|---|---|---|
| **Blue/Green Asym. Div.** | 1.59E-12 | 6.80E-10 | 8.21E-16 | 3.78E-07 | 8.37E-08 | 2.61E-05 |
| **Gold/Grey** | 1.63E-09 | 6.38E-05 | 4.53E-09 | 0.110 | 9.92E-03 | |
| **Autumn** | 2.05E-04 | 0.292 | 3.67E-05 | 0.965 | | |
| **Extended Cool/Warm** | 1.02E-06 | 0.248 | 1.36E-08 | | | |
| **Heat Map** | 0.920 | 1.00 | | | | |
| **Rainbow** | 7.69E-05 | | | | | |

# What Affects the Counts?

- Participants also provided information about age, gender, and education level.

# What Affects the Counts?

- Participants also provided information about age, gender, and education level.
- We want to understand how these affect the number of perceived colors.



Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

# What Affects the Counts?

- Participants also provided information about age, gender, and education level.
- We want to understand how these affect the number of perceived colors.
- Looked first at graphical analysis using dendrograms.

# What Affects the Counts?

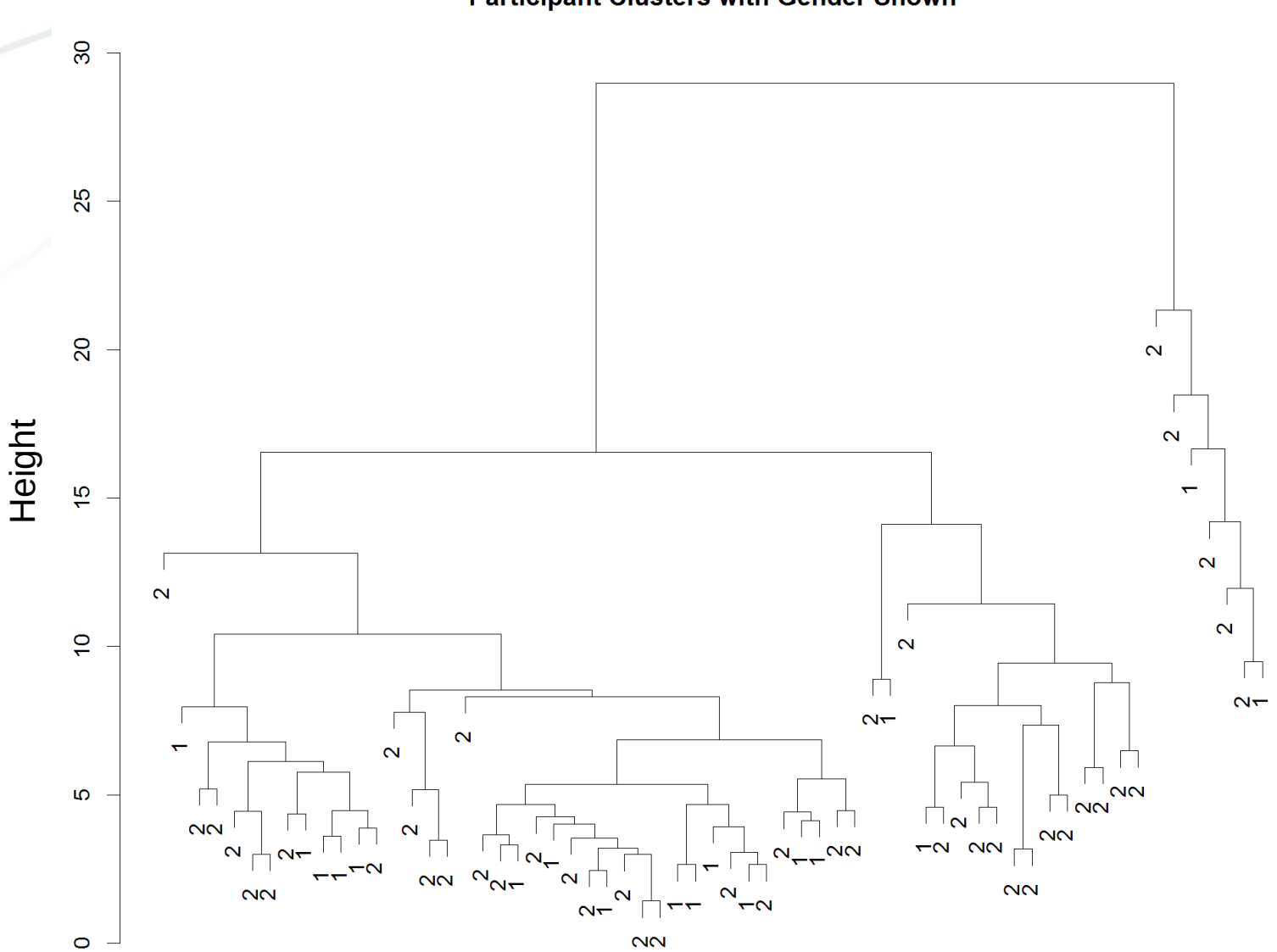
- Participants also provided information about age, gender, and education level.
- We want to understand how these affect the number of perceived colors.
- Looked first at graphical analysis using dendrograms.
- Created a linear model.



NNSA National Nuclear Security Administration

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

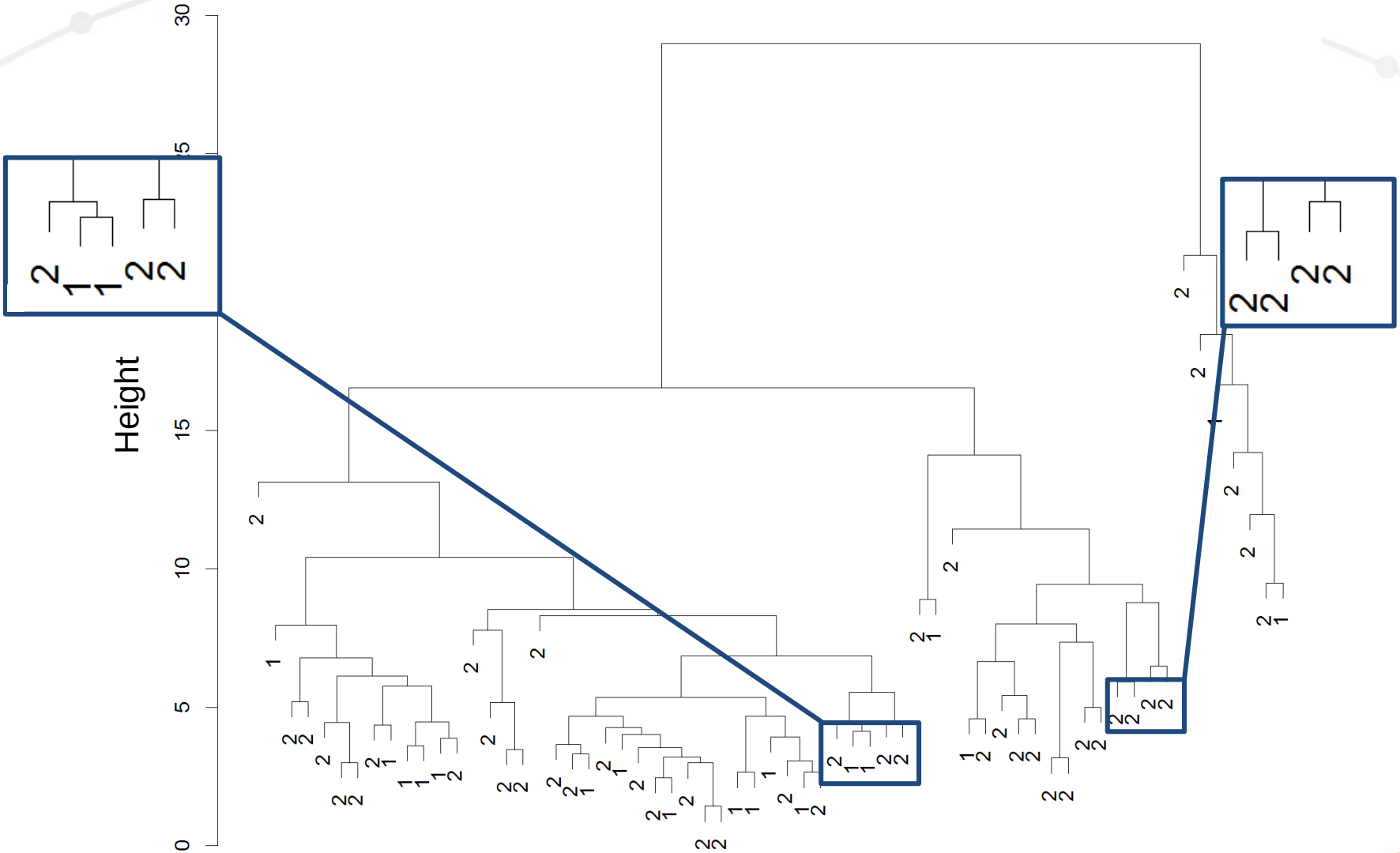
Los Alamos NATIONAL LABORATORY EST. 1943






Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

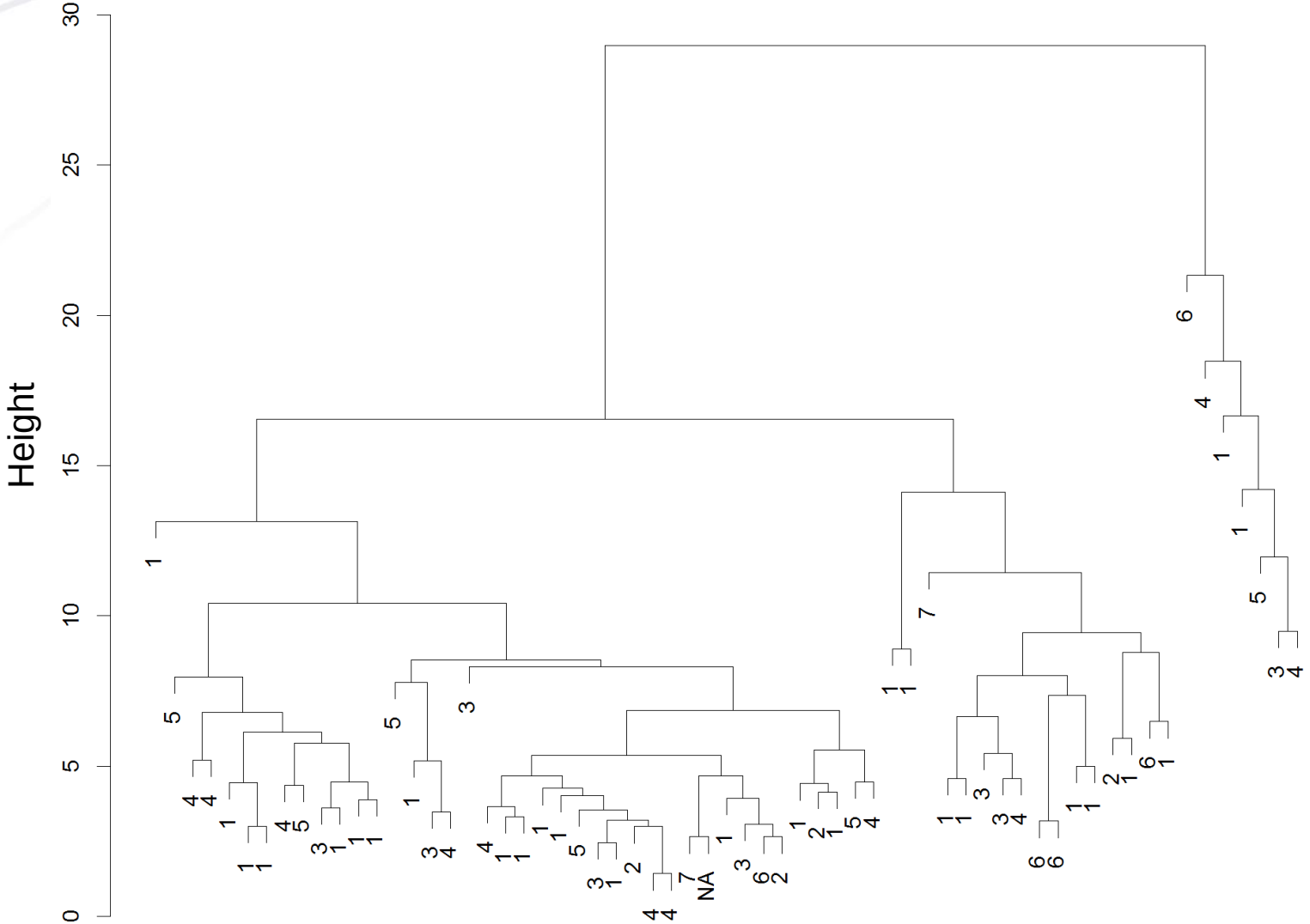
## Participant Clusters with Gender Shown






NNSA National Nuclear Security Administration
Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA
Los Alamos NATIONAL LABORATORY EST. 1943

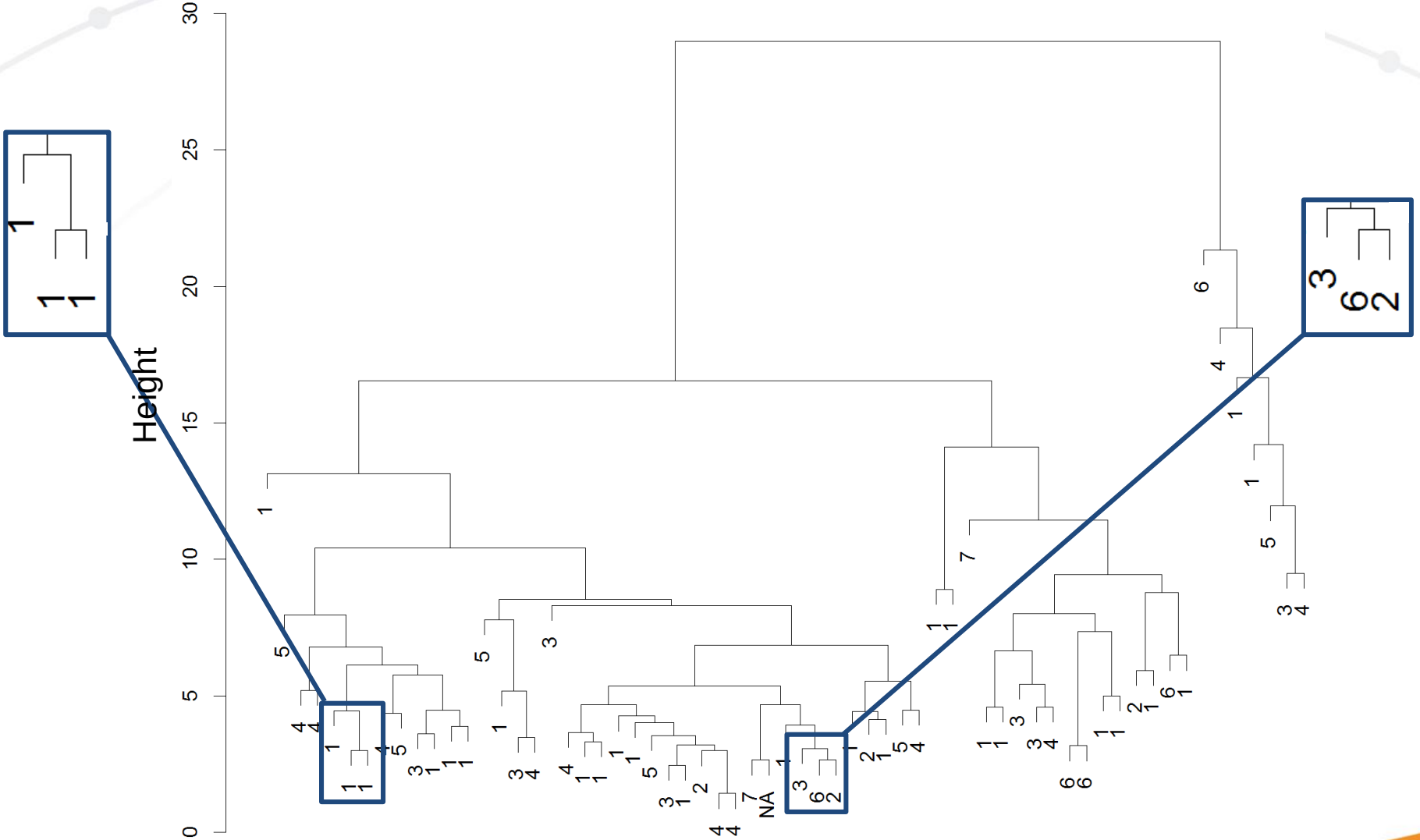
## Participant Clusters with Age Shown





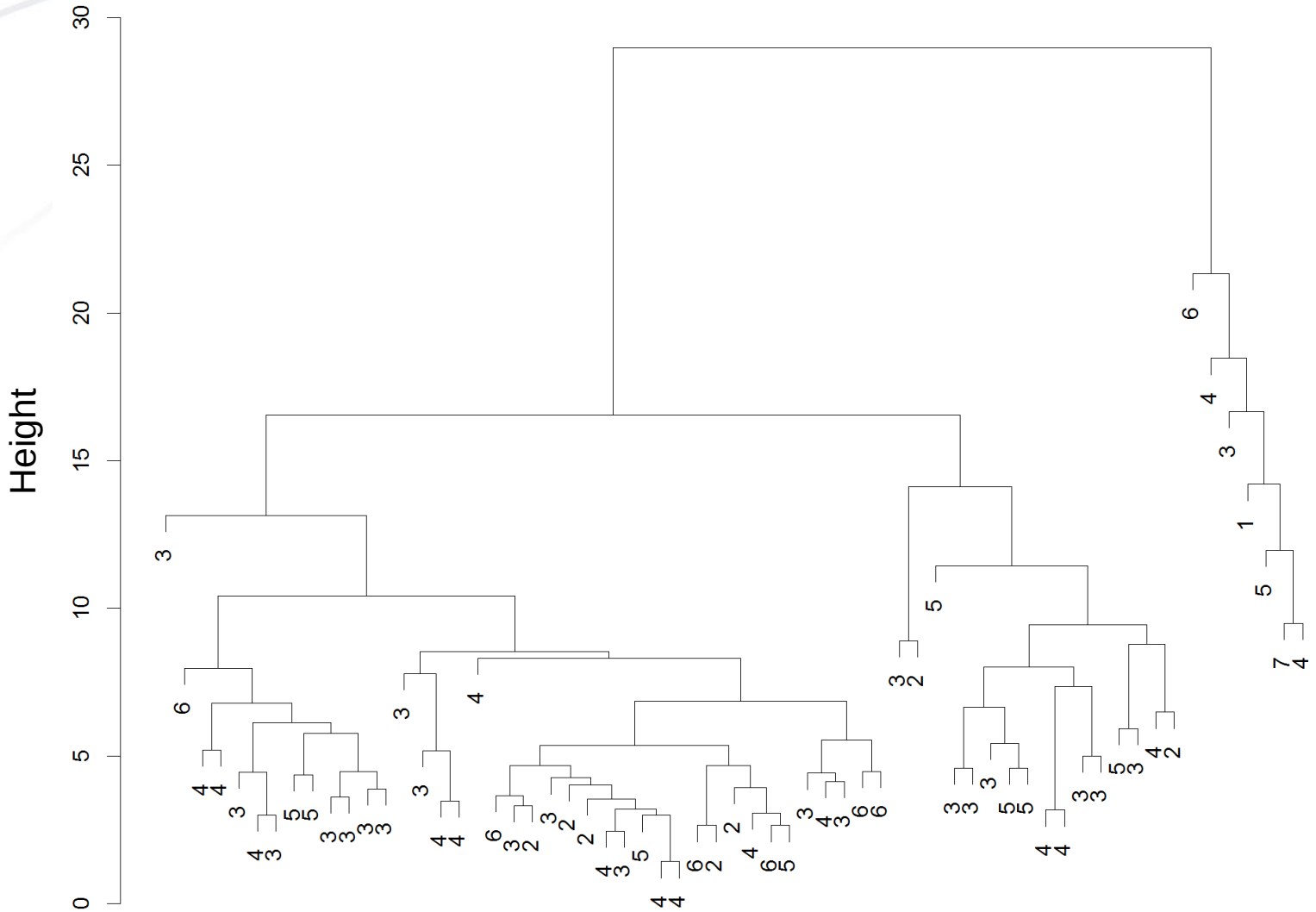

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

## Participant Clusters with Age Shown




UNCLASSIFIED

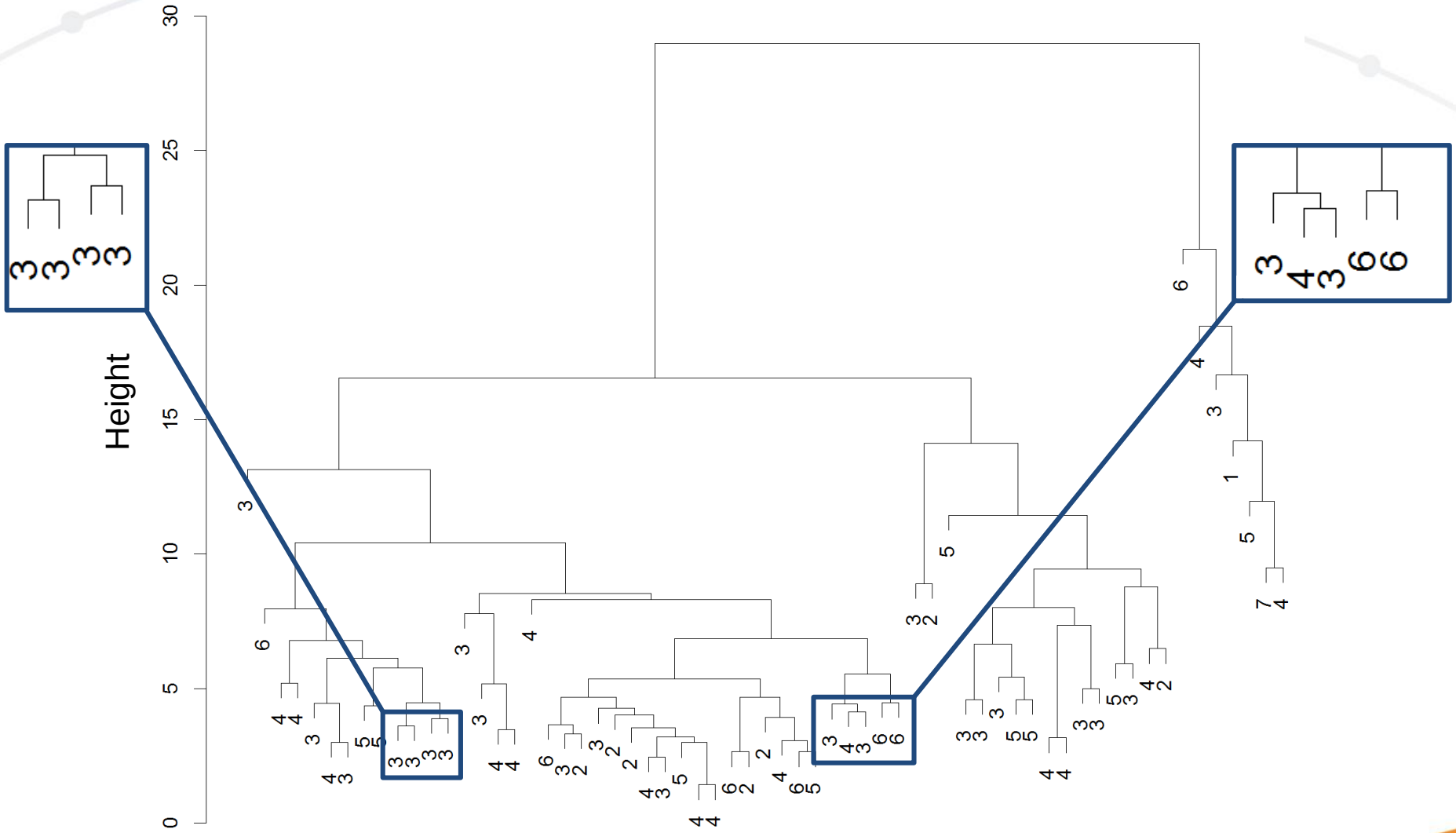
## Participant Clusters with Education Shown






NNSA National Nuclear Security Administration
Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA
Los Alamos NATIONAL LABORATORY EST. 1943

## Participant Clusters with Education Shown






NNSA National Nuclear Security Administration
Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA
Los Alamos NATIONAL LABORATORY EST. 1943

# Modeling the Counts

- Want to have a model to better understand the interaction of other variables with colormaps on the count of perceived colors.

# Modeling the Counts

- Want to have a model to better understand the interaction of other variables with colormaps on the count of perceived colors.
- Parameterization

# Modeling the Counts

- Want to have a model to better understand the interaction of other variables with colormaps on the count of perceived colors.
- Parameterization
  - Map: Categorical Variable (Columns of 1's and 0's)
    - 1: Gold/Grey
    - 2: Autumn
    - 3: Blue/Green Asym. Div.
    - 4: Extended Cool/Warm
    - 5: Heat Map
    - 6: Rainbow
    - 7: Cool Warm

# Modeling the Counts

- Want to have a model to better understand the interaction of other variables with colormaps on the count of perceived colors.
- Parameterization
  - Map: Categorical Variable (Columns of 1's and 0's)
  - Education: 1-8
    - 1: Some High School
    - 2: High School Diploma or GED
    - 3: Some College of Associate Degree
    - 4: Undergraduate Degree
    - 5: Masters Degree
    - 6: Doctorate or Professional Degree
    - 7: Other (Please Explain)
    - 8: Prefer Not to Respond

# Modeling the Counts

- Want to have a model to better understand the interaction of other variables with colormaps on the count of perceived colors.
- Parameterization
  - Map: Categorical Variable (Columns of 1's and 0's)
  - Education: 1-8
  - Age: 1-7
    - 1: 18-25
    - 2: 26-30
    - 3: 31-40
    - 4: 41-50
    - 5: 51-60
    - 6: 61-70
    - 7: 71+

# Modeling the Counts

- Want to have a model to better understand the interaction of other variables with colormaps on the count of perceived colors.
- Parameterization
  - Map: Categorical Variable (Columns of 1's and 0's)
  - Education: 1-8
  - Age: 1-7
  - Gender
    - 1: Male
    - 2: Female
    - 3: Other/Prefer not to Respond

# Modeling the Counts

| $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | $X_7$ | $X_8$ | $X_9$ | $X_{10}$ |
|---|---|---|---|---|---|---|---|---|---|
| Gold/Grey | Autumn | Blue/Green Asym. Div. | Extended Cool/Warm | Heat Map | Rainbow | Cool/Warm | Gender | Education | Age |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 6 | 5 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 5 | 7 |
| 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 2 |
| 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 2 | 6 |
| 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 3 | 3 |
| 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 4 | 5 |
| … | … | … | … | … | … | … | … | … | … |

# Modeling the Counts

$$Y = 14.012X_1 + 12.9728X_2 + 16.1502X_3 + 13.5695X_4 + 10.6663X_5 + 12.3760X_6 + 11.1663X_7 + 0.2335X_8 - 0.0941X_9 + 0.0682X_{10}$$

# Modeling the Counts

- Look at a t-test for the coefficients.



NNSA National Nuclear Security Administration

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

Los Alamos NATIONAL LABORATORY EST. 1943

# Modeling the Counts

- Look at a t-test for the coefficients.
- $H_0$: The true coefficient is zero.



Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

# Modeling the Counts

- Look at a t-test for the coefficients.
- $H_0$: The true coefficient is zero.
- $H_1$: The true coefficient is not zero.

# Modeling the Counts

| | t Value | Pr(>\|t\|) |
|---|---|---|
| **Gold/Grey** | 11.309 | <0.0001 |
| **Autumn** | 10.463 | <0.0001 |
| **Blue/Green Asym. Div.** | 13.026 | <0.0001 |
| **Extended Cool/Warm** | 10.945 | <0.0001 |
| **Heat Map** | 8.604 | <0.0001 |
| **Rainbow** | 9.983 | <0.0001 |
| **Cool/Warm** | 9.007 | <0.0001 |
| **Gender** | 0.445 | 0.656 |
| **Education** | -0.390 | 0.697 |
| **Age** | 0.422 | 0.674 |

# Modeling the Counts

| | t Value | Pr(>\|t\|) |
|---|---|---|
| **Gold/Grey** | 11.309 | <0.0001 |
| **Autumn** | 10.463 | <0.0001 |
| **Blue/Green Asym. Div.** | 13.026 | <0.0001 |
| **Extended Cool/Warm** | 10.945 | <0.0001 |
| **Heat Map** | 8.604 | <0.0001 |
| **Rainbow** | 9.983 | <0.0001 |
| **Cool/Warm** | 9.007 | <0.0001 |
| **Gender** | 0.445 | 0.656 |
| **Education** | -0.390 | 0.697 |
| **Age** | 0.422 | 0.674 |

# Modeling the Counts

| | t Value | Pr(>\|t\|) |
|---|---|---|
| **Gold/Grey** | 11.309 | <0.0001 |
| **Autumn** | 10.463 | <0.0001 |
| **Blue/Green Asym. Div.** | 13.026 | <0.0001 |
| **Extended Cool/Warm** | 10.945 | <0.0001 |
| **Heat Map** | 8.604 | <0.0001 |
| **Rainbow** | 9.983 | <0.0001 |
| **Cool/Warm** | 9.007 | <0.0001 |
| **Gender** | 0.445 | 0.656 |
| **Education** | -0.390 | 0.697 |
| **Age** | 0.422 | 0.674 |

# Conclusions

- The new colormaps all had higher counts than the traditional Cool/Warm and Heat Map.
- Extended Cool/Warm and Autumn couldn’t be proven to produce different counts than Rainbow.
- Blue Green Asymmetric Divergent had the highest counts of all.
- Age, gender, and education have no significant impact on the number of perceivable colors.

# Acknowledgements


- This work was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Science Undergraduate Laboratory Internships Program (SULI).

# Questions?