

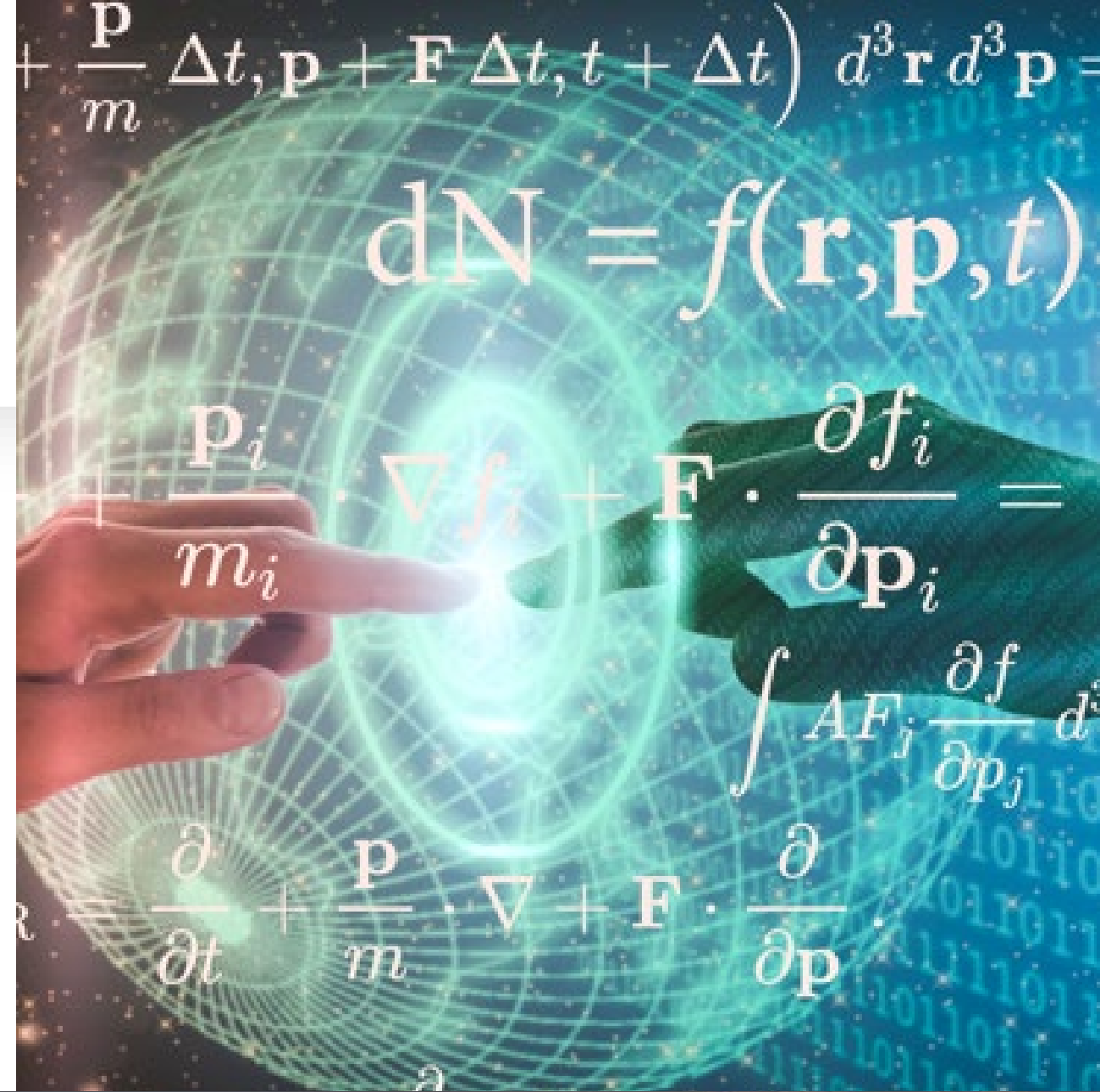
# Welcome

## -- Teaming4BDT!

2024 Interagency Modeling and Analysis Group (IMAG) - Multiscale Modeling (MSM) Consortium Meeting

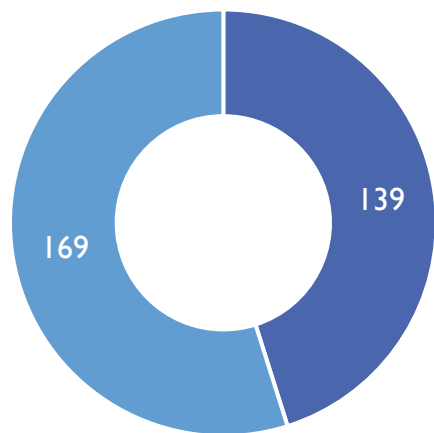
### Setting Up Teams for Biomedical Digital Twins

- September 30 – October 2, 2024



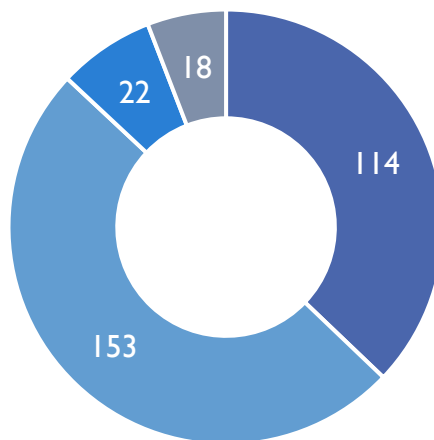
# AUDIENCE PROFILE

### Attendance Method



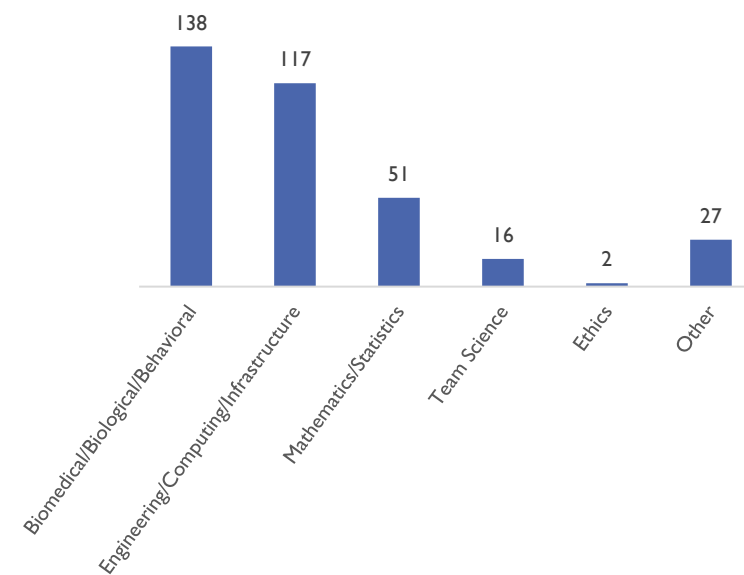
■ Attending Virtually ■ Attending in Person

### Audience Affiliation



■ Federal Employee/Contractor ■ Academia ■ Industry ■ Other

### Area of Expertise



# IMAG Interagency Modeling And Analysis Group



MULTISCALE MODELING CONSORTIUM



National Institute of Biomedical Imaging and Bioengineering



Society for Mathematical Biology

Thank you to our sponsors!

# The 2024 Teaming4BDT Planning Committee

- Gary An, MSM
- Jeff Buchsbaum, IMAG
- Julia Berzhanskaya, IMAG
- Caroline Chung, MSM
- Hannah Dueck, IMAG
- Fariba Fahroo, IMAG
- Zhilan Feng, IMAG
- Yulia Gel, IMAG
- Yuliya Gorb, IMAG
- Peter Hunter, MSM
- Bruce Lee, MSM
- Carlos Lopez, MSM
- Orlando Lopez, IMAG
- Feilim Mac Gabhann, MSM
- Virginia Pasour, IMAG
- Eric Stahlberg, MSM

## IMAG Co-Chairs

Grace Peng, NIBIB  
Reed Shabman, NIAID  
Elizabeth Ginexi, NCCIH

Booklet  
Page 3

## PRESENTERS, MODERATORS, & SCRIBES



Gary An  
[Gary An, MD | The University of Vermont Health Network \(uvmhealth.org\)](#)



Michelle Bennett  
[LMBennett Team Consulting \(https://www.lmbennettconsulting.com/\)](#)



Julia Berzhanskaya  
[NIH-NHLBI | Interagency Modeling and Analysis Group \(nih.gov\)](#)

---

## PRESENTERS, MODERATORS, & SCRIBES



Jeffrey Buchsbaum  
[DR. JEFF BUCHSBAUM |](#)  
[About RRP | RRP](#)  
[\(cancer.gov\)](#)



Anirban Chaudhuri  
[Anirban Chaudhuri](#)



Caroline Chung  
[Caroline Chung | MD](#)  
[Anderson Cancer Center](#)

## PRESENTERS, MODERATORS, & SCRIBES



Hannah Dueck  
[Hannah Dueck, Ph.D. - NCI \(cancer.gov\)](#)

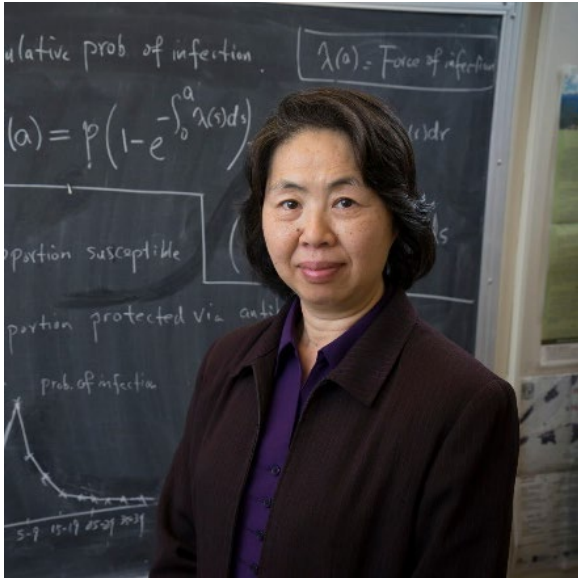


Barbara Evans  
[Barbara J. Evans » Levin College of Law \(ufl.edu\)](#)



Fariba Fahroo  
[Fariba Fahroo - Wikipedia](#)

# PRESENTERS, MODERATORS, & SCRIBES



**Zhilan Feng**  
[Zhilan Feng | NSF -  
National Science  
Foundation](#)



**Yulia Gel**  
[Yulia R. Gel  
\(utdallas.edu\)](#)



**Julian Goldman**  
[Julian Goldman, MD  
\(massgeneral.org\)](#)



## PRESENTERS, MODERATORS, & SCRIBES



**Yuliya Gorb**

[Yuliya Gorb | NSF - National Science Foundation](#)



**Peter Hunter**

[Peter Hunter Profile | University of Auckland](#)



**Reinhard Laubenbacher**

[Reinhard Laubenbacher » Laboratory for Systems Medicine » College of Medicine » University of Florida \(ufl.edu\)](#)

---

## PRESENTERS, MODERATORS, & SCRIBES



**Bruce Lee**  
[Bio | Bruce Y. Lee, MD,  
MBA \(bruceylee.com\)](#)



**Carlos F. López**  
[Carlos Lopez, Ph.D., Altos  
Laboratories - Model Certainty in  
Biochemical Reaction Networks |  
Department of Bioengineering |  
UC Santa Barbara \(ucsb.edu\)](#)



**Orlando Lopez**  
[Orlando Lopez, Ph.D. |  
National Institute of  
Dental and Craniofacial  
Research \(nih.gov\)](#)

## PRESENTERS, MODERATORS, & SCRIBES



William W. Lytton  
[William W. Lytton, MD |  
Faculty | Pharmacology |  
SUNY Downstate](#)



Feilim Mac Gabhann  
[Feilim Mac Gabhann -  
Johns Hopkins Whiting  
School of Engineering  
\(jhu.edu\)](#)



Maria Eduarda Montezzo  
Coelho  
[Maria Coelho — Idaho  
National Laboratory  
\(elsevierpure.com\)](#)

---

## PRESENTERS, MODERATORS, & SCRIBES



**Virginia Pasour**  
[Pasour, Virginia - Applied  
Physical Sciences  
\(unc.edu\)](#)



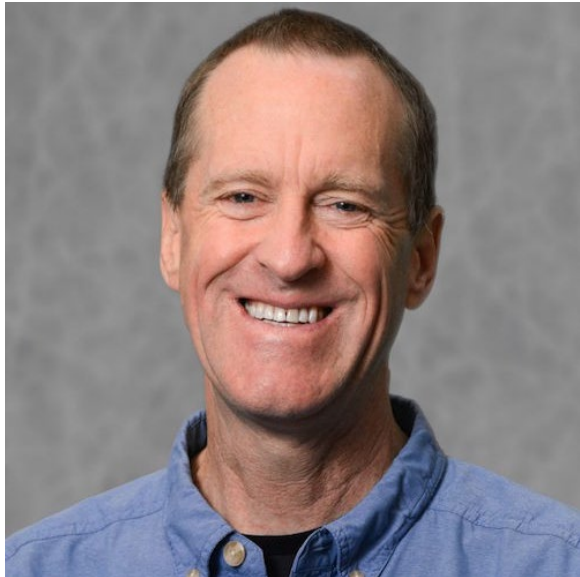
**Grace Peng**  
[Grace C.Y. Peng | National  
Institute of Biomedical Imaging  
and Bioengineering \(nih.gov\)](#)



**Elena Sizikova**  
[Elena Sizikova  
\(esizikova.github.io\)](#)

---

## PRESENTERS, MODERATORS, & SCRIBES



Ralph Smith  
[Ralph C. Smith \(ncsu.edu\)](mailto:ncsu.edu)



Eric Stahlberg  
[Eric A. Stahlberg |  
Frederick National  
Laboratory \(cancer.gov\)](mailto:cancer.gov)



Natalia Trayanova  
[Natalia Trayanova - Johns  
Hopkins Biomedical  
Engineering \(jhu.edu\)](mailto:jhu.edu)

---

## PRESENTERS, MODERATORS, & SCRIBES



Sandy Weinger

<https://www.researchgate.net/profile/Sandy-Weinger>

Thank You!!!

# IMAG wiki

Please use the IMAG wiki to post all your questions and comments during the meeting!

[www.imagwiki.nibib.nih.gov](http://www.imagwiki.nibib.nih.gov)

- Click on the agenda, and go to the link for the current session
- Post your Q&A and the speakers will respond there too!



# Agenda

## September 30, 2024 - Day 1: Defining Biomedical Digital Twins (BDT)

[Click Here](#) to view speaker information

Key:  BDT Project Idea,  BDT Components,  BDT Requirements,  Assessment Criteria

Time & Location	Activity	Organizers
8:00-8:30am Atrium, Poster Room	Check-in at Registration Set up posters	Registration Desk
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10:15-10:45am Cafeteria, Poster Rooms	AM Refreshments <a href="#">View Posters</a>	Refreshments Courtesy of the <a href="#">Society for Mathematical Biology</a>



# MAJOR ROLES

Moderator

Speaker/Panelist

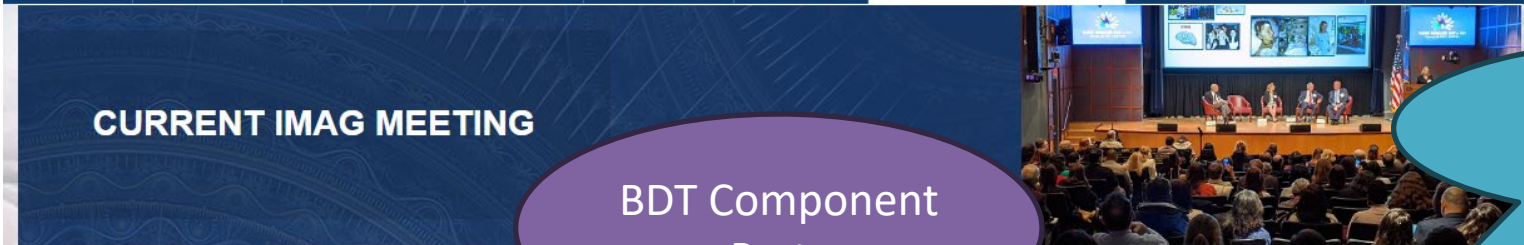
Scribe

The screenshot displays a webpage for the IMAG (Interagency Modeling and Analysis Group) website. The header includes the U.S. Department of Health & Human Services logo and the IMAG logo. A navigation bar contains links for HOME, ABOUT IMAG, and NEWS. The main content area is titled "1.6 - Breakout Session 1: Generating Requirements for BDT". Below the title, there are links for "Log in or register to post comments" and "Back to 2024 Agenda". The "Breakout Session Goal" is stated as "To develop requirements for BDTs". The "Charge to Speakers" section states: "The lead for each breakout room will present their thoughts for what they think (straw person) the BDT requirements should be, based on the Group Discussion Questions, below. They will show their starting point using a Miro board or slides. There will be two rounds of this exercise." The "Charge to Scribes" section is partially visible. A floating window on the right side of the page lists the session details:

- Session #1: Generating Requirements for BDT**
- Breakout Room A:** Verification, Validation, and Uncertainty (VVUQ); Mathematical and Statistical Foundations for BDT
- Breakout Room B:** Physical Assets/Data Collection/Sensors; Virtual to Physical Control Algorithms/Expert in the Loop
- Breakout Room C:** Ethical, Security Issues; Team Science, Governance

The floating window also lists the scribes for each room:

- Introduction:** Michelle Bennett
- Breakout Room A:** Reinhard Laubenbacher, Anirban Chaudhuri  
Scribes: Virginia Pasour, Fariba Fahroo
- Breakout Room B:** Julian Goldman, Sandy Weininger  
Scribes: Julia Berzhanskaya, Yulia Gel
- Breakout Room C:** Barbara Evans, Michelle Bennett  
Scribes: Hannah Dueck, Elena Sizikova

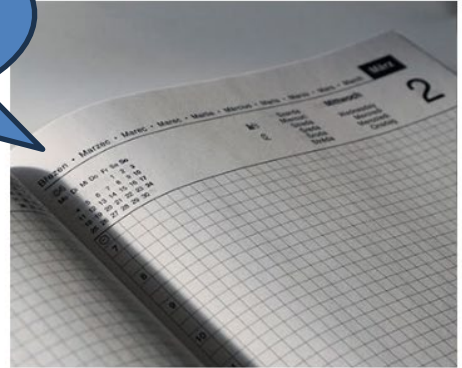


CURRENT IMAG MEETING

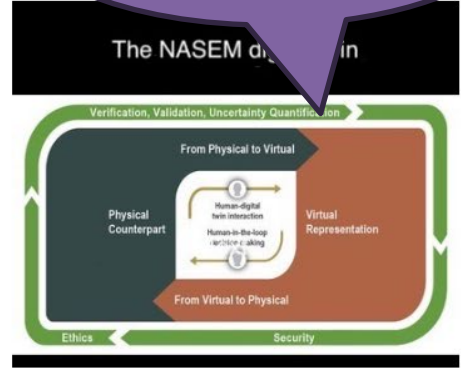
Day 1 & Day 2 Presenters

BDT Component Parts

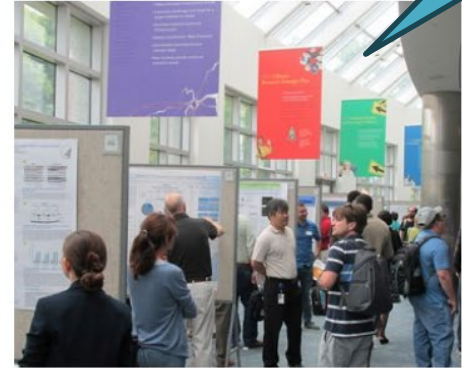
Post your comments in the session pages



Agenda >



Biomedical Digital Twin Networking Resources >



Posters & Presentations >

Not too late to submit your final PDFs!

Search for your Team

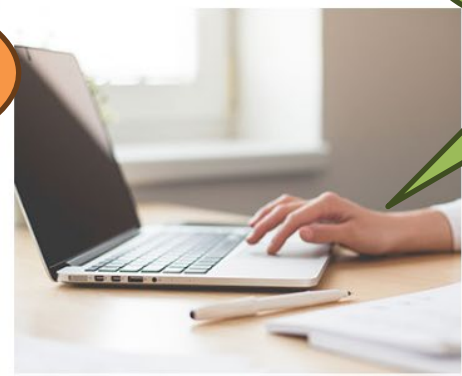


Attendees >

Where are we meeting for Bocce Ball?



Logistics >



Submit Materials (you must be registered and logged in) >

# NETWORKING EVENTS

## Day 1

**Attended Poster Session** - Poster Rooms

(10:15 - 10:45am, 4:00 - 4:30pm)

**Lunch and Networking** - Pike & Rose

(11:45 - 1:00pm)

**Happy Hour and Dinner** - Pinstripes  
Bethesda

(5:30 - 7:00pm)

11920 Grand Park Ave.  
North Bethesda, MD 20852

## Day 2

**Attended Poster Session** - Poster Rooms

(10:15 - 10:45am, 2:45 - 3:15pm)

**Lunch and Networking** - Pike & Rose

(12:00 - 1:15pm)

## Day 3

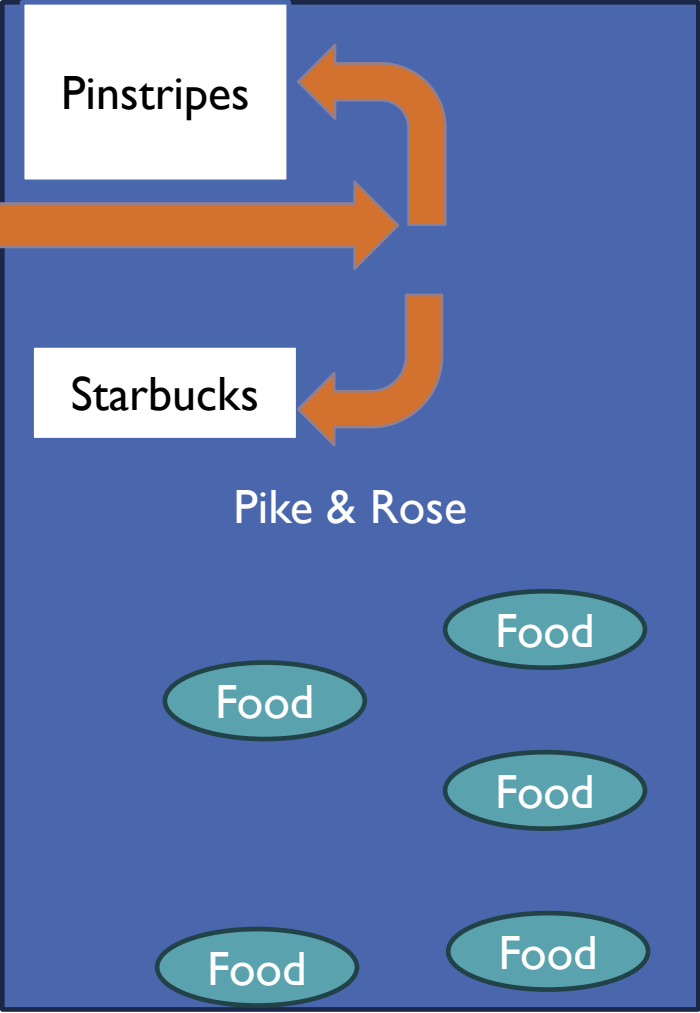
**Attended Poster Session** - Poster Rooms

(10:00 - 10:30am)

**Lunch and Networking** - Pike & Rose

(12:30 - 1:45pm)

# Covered Parking



# Open Parking

# Remember the BELL?



- Dedicated timer on podium
- 1 ring on bell – 2 minutes left
- 2 rings - please stop

# Foundational Research Gaps and Future Directions for Digital Twins

*Karen Willcox (chair), Caroline Chung, Jim Kinter,  
Irene Qualters, Brittany Segundo*

*December 15, 2023*

[https://www.nationalacademies.org/  
digital-twins](https://www.nationalacademies.org/digital-twins)



# Report Snapshot



0. Summary
1. Introduction
2. The Digital Twin Landscape
3. Virtual Representation
4. The Physical Counterpart
5. Feedback Flow from Physical to Virtual
6. Feedback Flow from Virtual to Physical
7. Towards Scalable and Sustainable Digital Twins
8. Summary of Findings, Conclusions, and Recommendations

**48**

Gaps

**22**

Findings

**19**

Conclusions

**8**

Recommendations

Digital Twin?



Digital Twin?

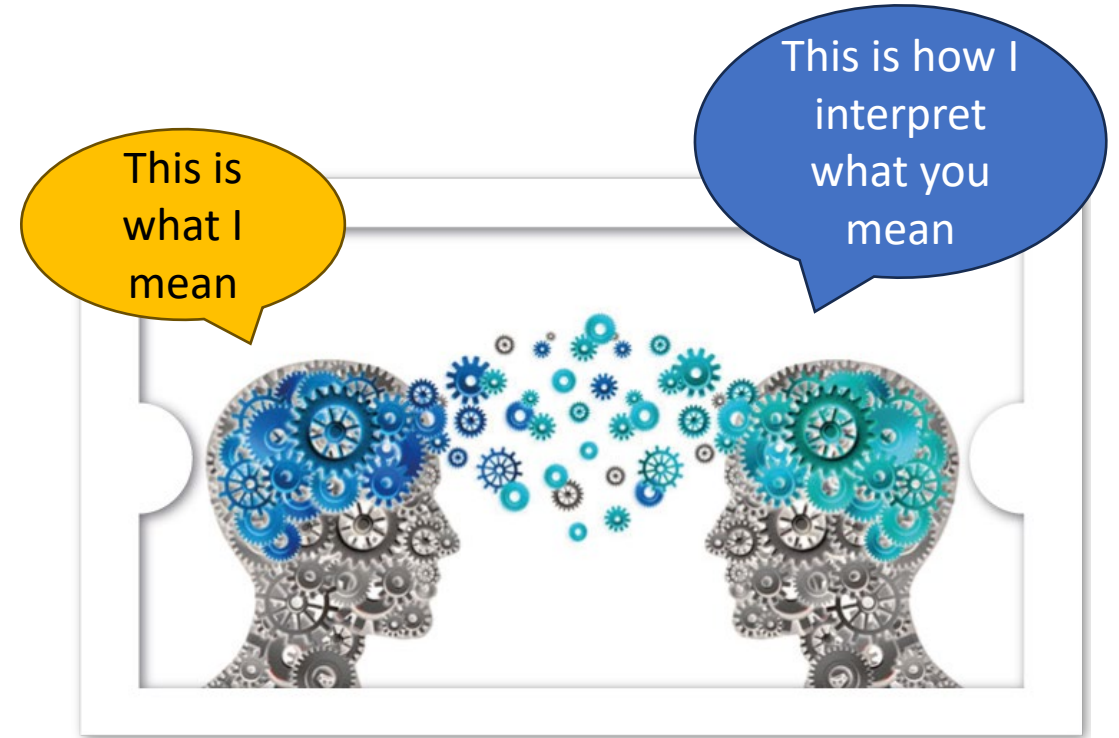
Biomedical Digital Twin?



Digital Twin?

Digital Twin?

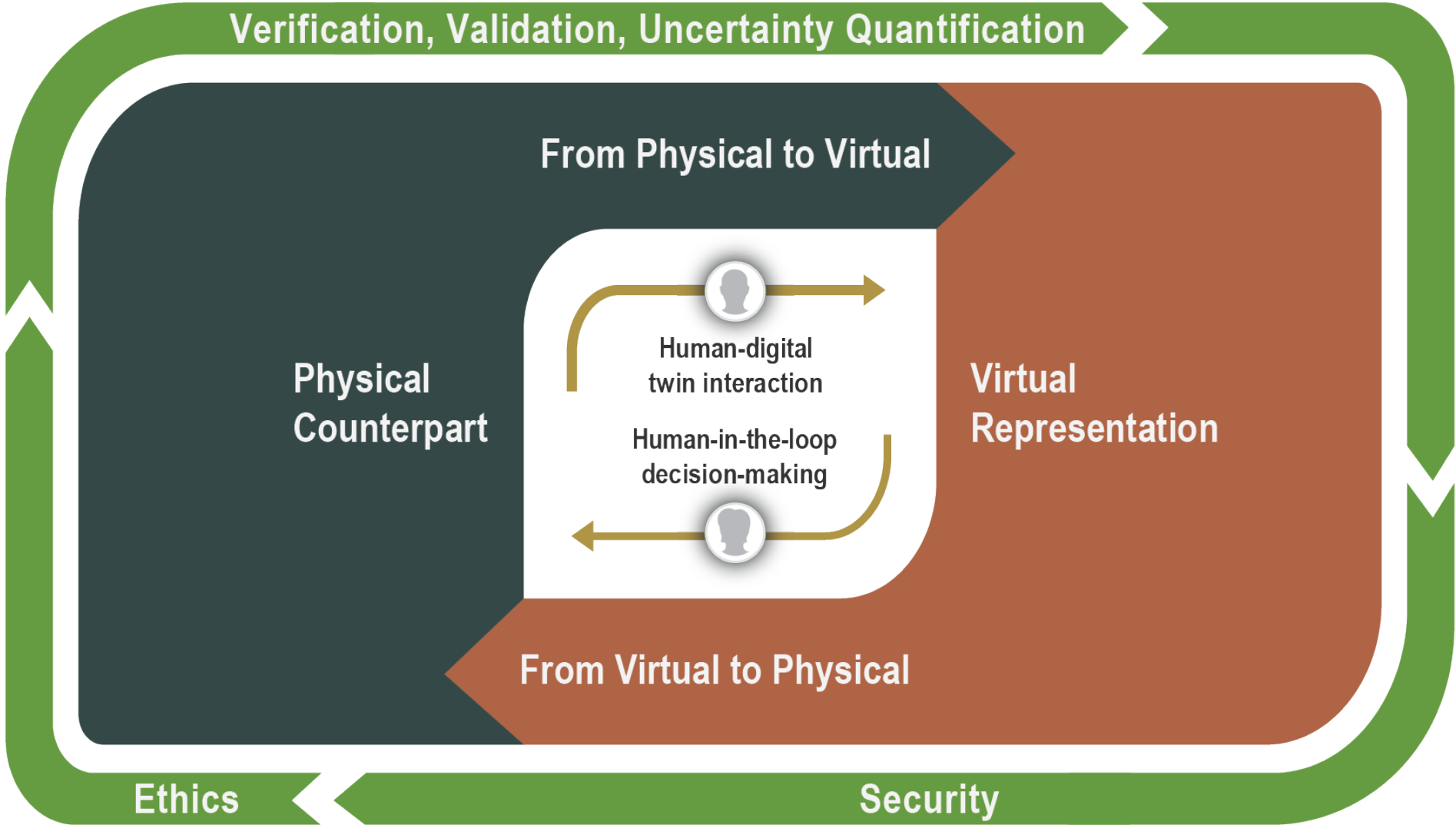
Biomedical Digital Twin?



**Let's use the same benchmark!**



# A Digital Twin is More Than Just Simulation and Modeling



## Setting up TEAMS for Biomedical Digital Twins (Teaming4BDT)



$$f\left(\mathbf{r} + \frac{\mathbf{p}}{m} \Delta t, \mathbf{p} + \mathbf{F} \Delta t, t + \Delta t\right) d^3 \mathbf{r} d^3 \mathbf{p} = f(\mathbf{r}, \mathbf{p}, t) d^3 \mathbf{r} d^3 \mathbf{p}$$

$$dN = f(\mathbf{r}, \mathbf{p}, t) d^3 \mathbf{r} d^3 \mathbf{p}$$

$$\frac{\partial f_i}{\partial t} + \frac{\mathbf{p}_i}{m_i} \cdot \nabla f_i + \mathbf{F} \cdot \frac{\partial f_i}{\partial \mathbf{p}_i} = \left(\frac{\partial f_i}{\partial t}\right)_{\text{coll}}$$

$$\int A F_j \frac{\partial f}{\partial p_j} d^3 \mathbf{p} = -n F_j \left\langle \frac{\partial A}{\partial p_j} \right\rangle,$$

$$\hat{\mathbf{L}}_{\text{NR}} = \frac{\partial}{\partial t} + \frac{\mathbf{p}}{m} \cdot \nabla + \mathbf{F} \cdot \frac{\partial}{\partial \mathbf{p}}$$

$$\frac{\partial}{\partial t} \left(u + \frac{1}{2} \rho V_i V_i\right) + \frac{\partial}{\partial x_j} \left(u V_j + \frac{1}{2} \rho V_i V_i V_j + J_{qj} + P_{ij} V_i\right) - n F_i V_i = 0,$$

September 30 - October 2, 2024 | NIH Bethesda, MD



# Agenda

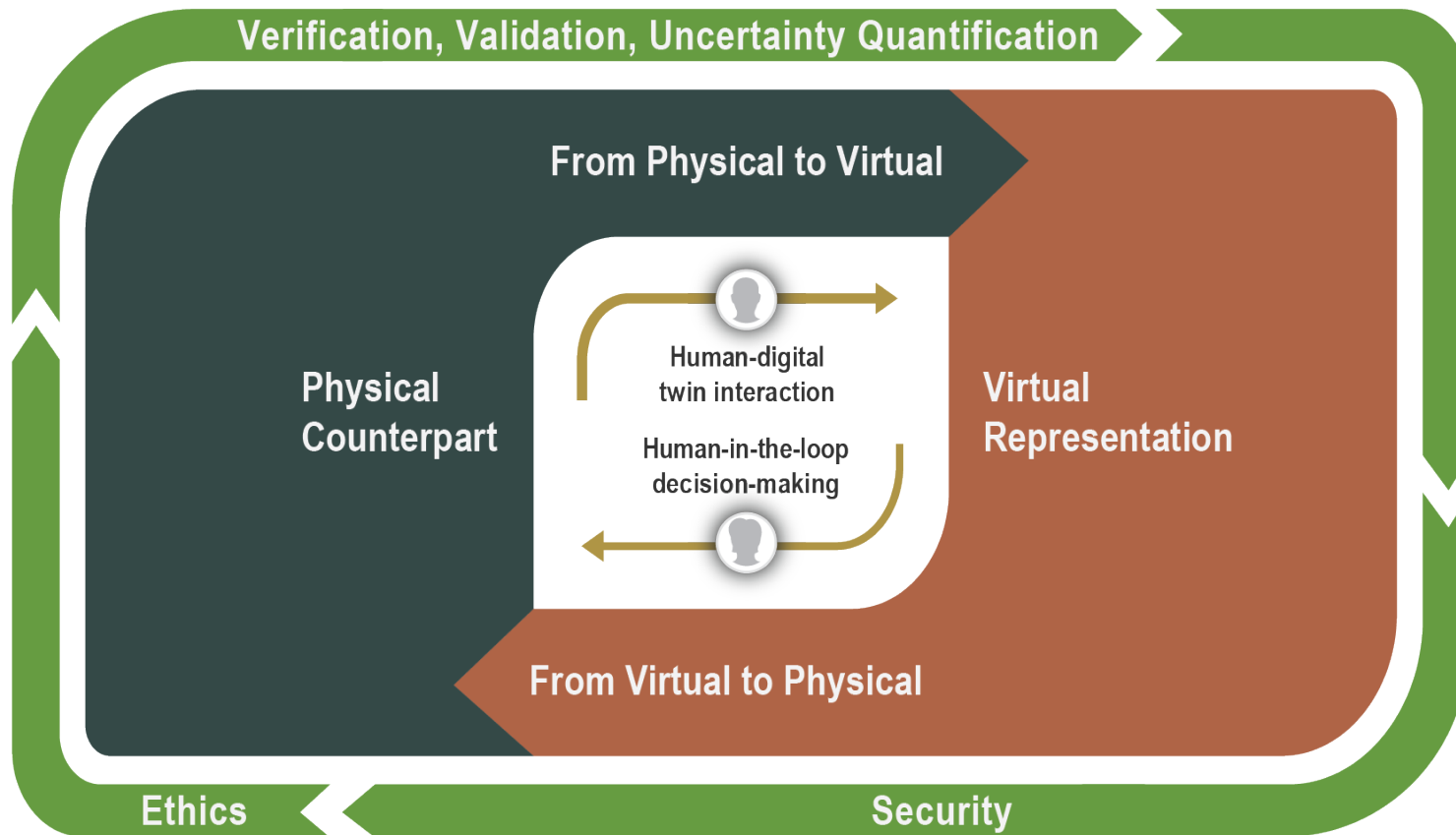
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# A Digital Twin is More Than Just Simulation and Modeling



## NASEM DT Components for discussion

1. Fit-for-Purpose BDT
2. Verification, Validation and Uncertainty Quantification (VVUQ)
3. Modularity/Interoperability/Systems of Systems mindset
4. Physical assets/data collection/sensors
5. Mathematical and statistical foundations for BDT
6. Virtual to Physical Control Algorithms/ Expert in the loop
7. Ethical, security issues
8. Sustainability, regulatory issues
9. Data/Knowledge systems

# Digital Twin Challenges

