Daylighting Challenges

*Daily & Seasonal variations*

*Discomfort/Disability Glare: too much contrast reduces visibility*
Spatially Augmented Reality (SAR) Projection

- Camera detects design geometry
- 6 projectors augment design
- Design sketched with foam-core walls

Tangible Interface for Architectural Design

- Exterior & interior walls
- Tokens for:
  - Windows
  - Wall/floor colors
  - North arrow

- Overhead camera
- Projection geometry
- Inferred design
Outline

• Architectural Daylighting Design & Spatially Augmented Reality
• Immersive Dynamic Projection Surfaces
• Global Illumination Compensation
• Daylighting Design User Studies
• Web-Based Architectural Sketching
• Other Simulations: e.g. Acoustics
  Other Applications: e.g. Gaming
• Visualization for Emergency Response
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Mobile walls with IR LEDs
"Dynamic Projection Surfaces for Immersive Visualization",
Theodore C. Yapo, Yu Sheng, Joshua Nasman, Andrew Dolce, Eric Li, and Barbara Cutler,
Ingredients for EMPAC Visualization:

- EMPAC Spaces
- EMPAC Equipment
- EMPAC Staff
- Reserving EMPAC Space/Equipment/Staff
- (Your) Visualization Ideas
- (Your) Technical Challenges
- (Your) People/Time

Students: Yu Sheng, Ted Yapo, Josh Nasman, Andrew Dolce, Eric Li, Chris Young
Funding from: IBM, NSF, Support from: EMPAC
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Unintended Scattering due to Projection on Complex Geometry

Can we do a better job reproducing the desired appearance?
Radiosity & Inverse Lighting

Radiosity: total reflected light
Form factor matrix: relationship between patches
Direct light: received/ emitted

\[ B = (I - F)^{-1} E \]
(forward) Radiosity

known lighting conditions \( E \),
solve for \( B \)

\[ E = (I - F)B \]
“Reverse Radiosity”
desired appearance \( B \),
solve for \( E \)

Reverse Radiosity

Clamped projection errors are most significant for high albedo projection surfaces and lower albedo desired virtual environments.
Our Optimization Formulation

Absolute Error:
\[ \phi_{abs} = \frac{\sum_i A_i [(L_i - L_i')^2 + (a_i - a_i')^2 + (b_i - b_i')^2]}{A_{avg}} \]

Spatial Error:
\[ \phi_{sp} = \sum_{(i,j) \in \text{enbd}} [(L_i - L_j) - (L_i' - L_j')]^2 + [(a_i - a_j) - (a_i' - a_j')]^2 \]
\[ + [(b_i - b_j) - (b_i' - b_j')]^2 \]

Complete Objective Function:
\[ \phi = \alpha \phi_{abs} + (1 - \alpha) \phi_{sp} \]

Box constraints:
minimum & maximum brightness of projector system

We use \( \alpha = 0.9 \)

Our Compensated Projection Result

“Global Illumination Compensation for Spatially Augmented Reality”
Yu Sheng, Theodore C. Yapo, and Barbara Cutler
Perceptual Global Illumination Cancellation in Complex Projection Environments
Yu Sheng, Barbara Cutler, Chao Chen, and Joshua Nasman
Eurographics Symposium on Rendering, June 2011.
Performance Comparison with other Non-Linear Least Squares solvers

MATLAB lsqnonlin: trust-region
  in MATLAB (early tests ~30 minutes on small model)
Levenberg-Marquadt based solver in C
  in C++ (32-50 seconds)

Our method, using CUDA (1.8-2.4 seconds)
  NVIDIA GeForce GTX 480 graphics card
  Intel Core 2 Quad Q9450 CPU
  CUBLAS, CUSPARSE, Thrust, CULA, GPU LAPACK
  single precision floating point computation

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Watertight Mesh for Simulation

Detected geometry

Projection surfaces

“Fill-in” geometry

“Extra” physical geometry

(model interior)
Linking Elements to Form Chains

- If $A \rightarrow B$ and $B \rightarrow A$ are best matches for tangent, then the walls are joined into a chain

Halfspace Zones & Enclosure

- Further subdivided using GraphCuts (if needed)
Interior/Exterior Enclosure Threshold

- Unfortunately, there is no universal threshold
- Varies design-to-design, and within-a-design

![Automatic Interior/Exterior Determination & Final Floorplan](image1)

Interior/Exterior Optimization

- Analyze histogram of point-sampled enclosure values
- Maximize usage of lengths of real wall elements
- Minimize length of inferred (added) walls
- Minimize area assigned in opposition of simple threshold metric

![Complex Boundaries & Varying Gaps](image2)
Identify/Quantify Ambiguous Designs

User Study Models of Graphics Lab
Renderings of User Models

Accuracy in Modeling & Illumination
Glare avatars

- Specify intended use of space
- Both position and viewing direction specified
- Allow users to “put themselves into the room”

False Color Renderings of Specified Views

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Acoustics Simulation

- Study distribution of sound and echo patterns
- Use reflective/absorptive materials appropriately to distribute sound/reduce noise
Spatially Augmented Reality Games

“ARmy: A Study of Multi-User Interaction in Spatially Augmented Games”
Andrew Dolce, Joshua Nasman, and Barbara Cutler
PROCAMS June 2012.
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Emergency Response Decision Making

Full network detail is overwhelming
Subset of data

Zoom and "expand" information for critical nodes and network links

name: Child Residential Facilities
definition: Child Residential Facilities
type: Demand
power: 100%
water: 0%
waste: 100%
ID: 3109
Trace back problem to source of outage

Prioritize crew assignments
Conclusions

• Graphics & Visualization are fun
• Simulations can be complex with non-intuitive results
• Tool design must balance needs: ease-of-use, performance, accuracy, & feedback to user
• Effective collaborative & immersive interfaces are complicated to build
• Prototypes & user studies are necessary to validate your approach and often yield surprising results