THE DESIGN AND EVOLUTION OF THE UBERBAKE LIGHT BAKING SYSTEM

Dario Seyb¹, Peter-Pike Sloan², Ari Silvennoinen², Michał Iwanicki², Wojciech Jarosz¹
Evolve a static light baking system to support dynamic lights and geometry
Evolve a **static light baking** system to support **dynamic lights and geometry**
Evolve a **static light baking** system to support **dynamic lights and geometry**

- What major **changes** did we have to make?
Evolve a static light baking system to support dynamic lights and geometry

• What major **changes** did we have to make?
• Which **design decision** made the process easier?
Evolve a **static light baking** system to support **dynamic lights and geometry**

- What major **changes** did we have to make?
- Which **design decision** made the process easier?
- How did our **constraints** guide us to good solutions?
What is this talk *not* about?
What is this talk not about?

• No one specific new technique or technical contribution
What is this talk not about?

- No **one specific** new technique or technical contribution
- No **low level details** about data representations or code
What is this talk not about?

- No **one specific** new technique or technical contribution
- No **low level details** about data representations or code

*Peter-Pike is doing a session in Advances in Real-time Rendering*
Light Baking Preliminaries
Light Baking Preliminaries
Light Baking Preliminaries
Light Baking Preliminaries

- Precomputed Lighting
- Run-time Light Model

Final Lighting +
A basic system overview
A basic system overview

Level

Editor
A basic system overview

Bake Time

- Preprocess geometry
- Generate light map UVs
- Compute lighting
A basic system overview

Bake Time

- Preprocess geometry
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- Compute lighting

Level Editor

Compile Data
A basic system overview

### Bake Time
- Preprocess geometry
- Generate light map UVs
- Compute lighting

### Compile Data

### Run Time
- Render the scene!
Light Baking Preliminaries
Light Baking Preliminaries

• **Why** do we bake lighting?
It’s a matter of time
It’s a matter of time

60 Frames per Second
It’s a matter of time
It’s a matter of time

Time (ms)

Global Illumination
It’s a matter of time
It’s a matter of time

- Shadow Maps
- Volumetrics
- Primary Visibility
- Post Processing
- Global Illumination

Time (ms)
Light Baking Preliminaries

• **Why** do we bake lighting?
Light Baking Preliminaries

• **Why** do we bake lighting?
• **What** part of the lighting do we include?
All indirect lighting is baked
All indirect lighting is baked
Light Baking Preliminaries

• **Why** do we bake lighting?
• **What** part of the lighting do we include?
Light Baking Preliminaries

• **Why** do we bake lighting?
• **What** part of the lighting do we include?
• **How** do we do this efficiently?
Baking via series expansion
Baking via series expansion
Baking via series expansion
Baking via series expansion
Baking via series expansion

1. Inject Direct Lighting
Baking via series expansion

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Baking via series expansion

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Baking via series expansion
Baking via series expansion
Baking via series expansion

2. Gather Indirect
Baking via series expansion

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Baking via series expansion

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Baking via series expansion

2. Gather Indirect
Baking via series expansion

2. Gather Indirect
2. Gather Indirect with Path Guiding

[Silvennoinen and Sloan 2019]
Light Baking Preliminaries

- **Why** do we bake lighting?
- **What** part of the lighting do we include?
- **How** do we do this efficiently?
Light Baking Preliminaries

• **Why** do we bake lighting?
• **What** part of the lighting do we include?
• **How** do we do this efficiently?
Evolving UBERBAKE
Evolving UberBAKE
Evolving UberBake
Evolving UberBake

Static Lighting and Geometry

2016  2017  2019
Evolving UberBAKE

Static Lighting and Geometry

2016  2017  2019
Evolving UberBake

- Static Lighting and Geometry
- Dynamic Lighting

2016  2017  2019
The Design and Evolution of the UberBake Light Baking System
The Design and Evolution of the UberBake Light Baking System
We have a set of hard constraints...
We have a set of hard constraints...

C1: Near-zero *runtime overhead*
We have a set of hard constraints…

C1: Near-zero runtime overhead
C2: No additional constraints on geometry
We have a set of hard constraints...

C1: Near-zero *runtime overhead*

C2: No additional *constraints on geometry*

C3: No major revisions to *engine and tools code*
... and guiding goals
... and guiding goals

G1: Minimize artist iteration time
... and guiding goals

G1: Minimize artist iteration time

G2: Minimal content creation overhead
... and guiding goals

G1: Minimize artist iteration time
G2: Minimal content creation overhead
G3: Maximize implementation orthogonality
Making things more dynamic

**Precomputed Lighting**
(static lighting and geometry)

**Precomputed Light Transport**
(dynamic lighting, static geometry)

**Real-time Light Transport**
(dynamic lighting and geometry)

**Baked Lighting in Games**
[Barré-Brisebois 2017; Chen 2008; Guinier 2020; Iwanicki and Sloan 2017; Neubelt and Pettineo 2015; O’Donnell 2018; …]

**Precomputed Visibility**
[Christin 2018; Silvennoinen and Timonen 2015; Sloan et al. 2002; …]

**Direct to Indirect**
[Hašan et al. 2006; Kontkanen et al. 2006; Lehtinen et al. 2008; Martin and Einarsson 2010; …]

**Real-time GI**
[4A Games 2019; Hillair 2018; Remedy Entertainment 2019; Schied 2019; Majercik et al. 2019; …]

**Volumetric Scene Representation**
[Crassin et al. 2011; Kaplanyan and Dachsburger 2010; Laine and Karras 2010; Yudintsev 2019; …]
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- Baked Lighting in Games
  - [McTaggart 2004]

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Dynamic Lights in the Bake
Supporting dynamic lights
Supporting dynamic lights
Supporting dynamic lights
Supporting dynamic lights

Baked Lighting
Dynamic Light Sets (DLS)
Dynamic Light Sets (DLS)
Dynamic Light Sets (DLS)

Base Bake
Dynamic Light Sets (DLS)

DLS #1

Base Bake

DLS #1
Dynamic Light Sets (DLS)

DLS #1

DLS #2

Base Bake

DLS #1

DLS #2
Large memory requirements
Large memory requirements

- No DLS
- Naive
- Our

Memory Usage (MB)

- Estate
- Consulate
- Townhoused
- Safehouse
- Yard
Large memory requirements

- No DLS
- Naive
- Our

Memory Usage (MB)

- Estate
- Consulate
- Townhoused
- Safehouse
- Yard

Values:
- 0
- 1,000
- 2,000
- 3,000
- 4,000
Large memory requirements

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Sparse light maps for dynamic light sets

Base Bake

DLS #1

DLS #2
Sparse light maps for dynamic light sets

- Base Bake
- DLS #1
- DLS #2
Sparse light maps for dynamic light sets

Base Bake

DLS #1

DLS #2
Sparse light maps for dynamic light sets

Base Bake

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DLS #2
Reducing memory usage

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Reducing memory usage

Memory Usage (MB)

- **No DLS**
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Run-time combination of dynamic light sets

Base Bake

DLS #1

DLS #2

Final

The Design and Evolution of the UberBake Light Baking System
The Design and Evolution of the UberBake Light Baking System

Run-time combination of dynamic light sets

Base Bake

DLS #1

DLS #2

Final

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Base Bake

DLS #1

DLS #2

Final
Run-time combination of dynamic light sets

Base Bake

DLS #1

DLS #2

Final
Checkpoint reached.
The Design and Evolution of the UberBake Light Baking System
The Design and Evolution of the UberBake Light Baking System

Evolving UberBake

- Static Lighting and Geometry (2016)
- Dynamic Lighting (2017)
Dark Room
Dark Room

Non-Player Character

Door
Lit up room!
From dynamic lights to dynamic geometry
Geometry changes induce non-linear lighting effects
Geometry changes induce non-linear lighting effects
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Linearizing door lighting
Linearizing door lighting
Linearizing door lighting
Linearizing door lighting
Linearizing door lighting

![Diagram showing door lighting with irradiance and door opening axes.]

- **Irradiance**
  - 0
  - 0.25
  - 0.5
  - 0.75
  - 1

- **Door Opening**
  - 0
  - 1
Linearizing door lighting
Avoiding a combinatorial explosion
Avoiding a combinatorial explosion
Avoiding a combinatorial explosion
Avoiding a combinatorial explosion

Closed/Closed
Avoiding a combinatorial explosion
Avoiding a combinatorial explosion

Closed/Closed  Open/Closed  Closed/Open  Open/Open
Avoiding a combinatorial explosion

A * #1 Open + B * #2 Open
Splitting path space during the bake
Splitting path space during the bake
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Splitting path space during the bake
Splitting path space during the bake

Base Bake
Splitting path space during the bake

State #1

State #2
Splitting path space during the bake
Splitting path space during the bake

State #1

State #2
Splitting path space during the bake

State #1

State #2
Splitting path space during the bake
Splitting path space during the bake

State #1

State #2
Splitting path space during the bake

State #1

State #2
Splitting path space during the bake

State #1

State #2
Splitting path space during the bake

State #1

State #2
Further Simplifications

State #2
Further Simplifications

1. Disregard Bounce Light

State #2
Further Simplifications

1. Disregard Bounce Light

2. Ignore the "Open Door" geometry

State #2
Further Simplifications

Door Open
Further Simplifications

Door Open
Further Simplifications
Further Simplifications

Door Open
Further Simplifications

Door Open
Efficient Sampling
Efficient Sampling
Efficient Sampling
Efficient Sampling
Efficient Sampling
Efficient Sampling
Efficient Sampling
Efficient Sampling
Reusing Base Bake Information
Reusing Base Bake Information
Conclusion

Static Lighting and Geometry  2016

Dynamic Lighting  2017

Limited Dynamic Geometry  2019
Conclusion

Static Lighting and Geometry

Dynamic Lighting

Limited Dynamic Geometry

2016

2017

2019
Conclusion

- Static Lighting and Geometry
- Dynamic Lighting
- Limited Dynamic Geometry

2016 2017 2019
Conclusion

2016
Static Lighting and Geometry

2017
Dynamic Lighting

2019
Limited Dynamic Geometry

2020 and beyond

What’s next?
Conclusion

Static Lighting and Geometry
Dynamic Lighting
Limited Dynamic Geometry
Expand Dynamic Geometry

2016
2017
2019
2020 and beyond

What’s next?
Won’t better hardware solve this?
Won’t better hardware solve this?

• We are orders of magnitude off!
Won’t better hardware solve this?

• We are orders of magnitude off!
• We have to support old consoles.
Won’t better hardware solve this?

- We are orders of magnitude off!
- We have to support old consoles.
- Players are moving to mobile devices.
Won’t better hardware solve this?

• We are orders of magnitude off!
• We have to support old consoles.
• Players are moving to mobile devices.
• VR requires even higher frame rates.
Acknowledgements
Acknowledgements

• My co-authors!
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• Lighting artists Luka Romel, Vivian Ding, Dave Blizard, Omar Gatica, Velinda Reys, Krzystof Wojcik and Marko Vukovic
Thank you!

Please visit 
dartgo.org/uberbake
for the full paper and supplemental material

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Wojciech Jarosz
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