Digital Light Source Technology for Adaptive Lighting Systems

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Lumileds

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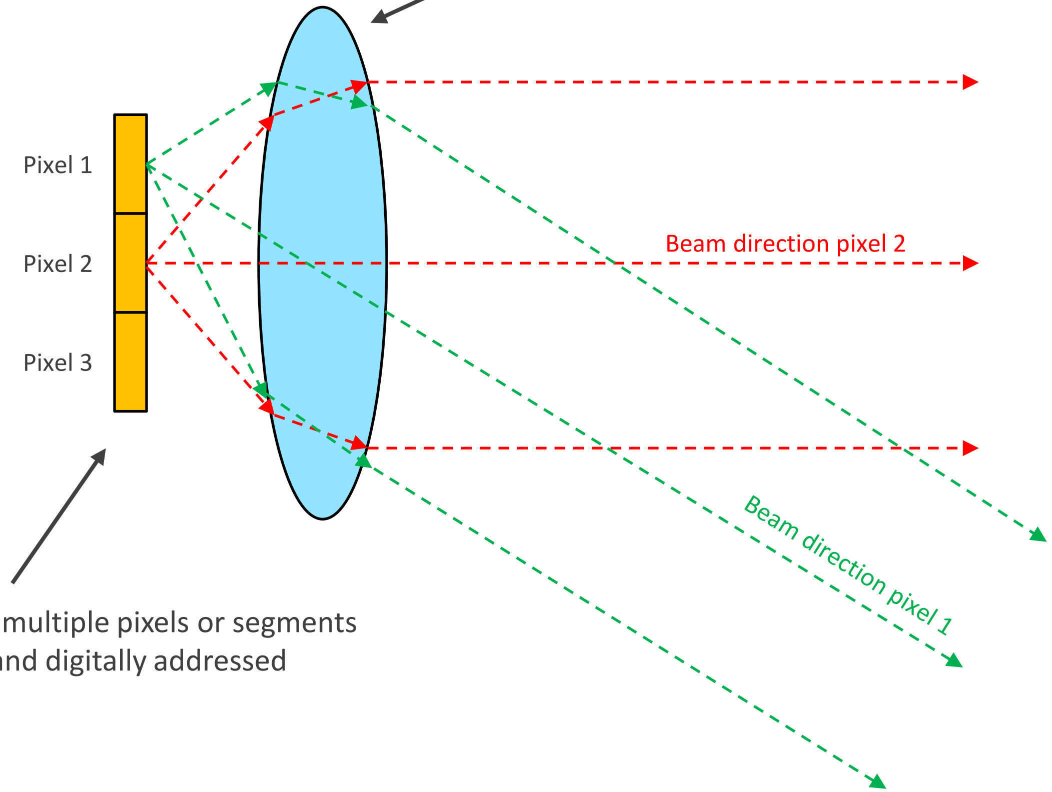
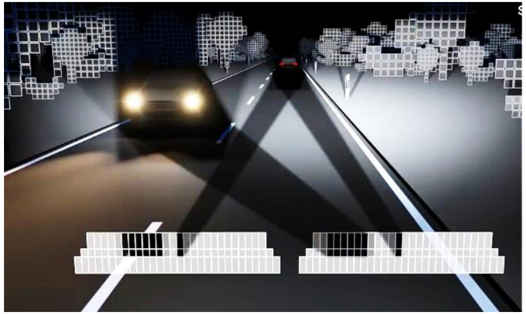
What is a digital light source?

Projection lens or other optic with defined correlation between source position and exit angle



LED source consisting of multiple pixels or segments that can be individually and digitally addressed

Digital light sources are transforming automotive headlighting…



…what benefits can they bring to general lighting applications?

Digital light source technology: from automotive to illumination applications

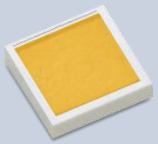
Automotive
Application characteristics

- Contrast over efficacy
- Color quality: cool white, color discrimination
- Complex lens system OK
- Image quality over efficiency
- Single application
- High pixel count, CMOS hybridization

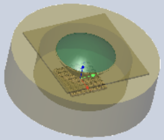
Illumination
Application characteristics

- Efficacy over contrast
- Color quality: full CCT range, high color fidelity, color tuning
- Single lens preferred
- Efficiency over image quality
- Scalable in area and flux
- Modular driver ICs, deep dimming and color control

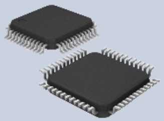
Illumination
Required technology elements



High luminance LEDs optimized for efficacy with illumination-grade phosphors



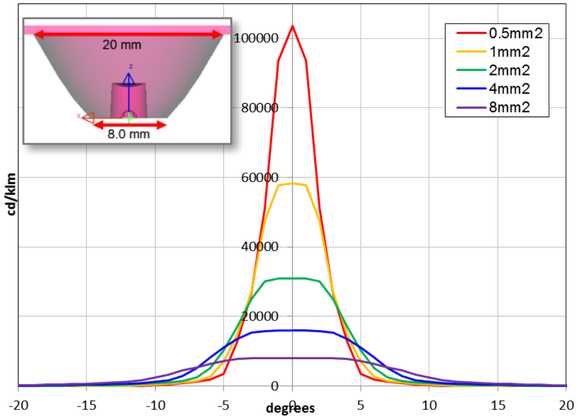
Scalable optical designs with illumination projection optics



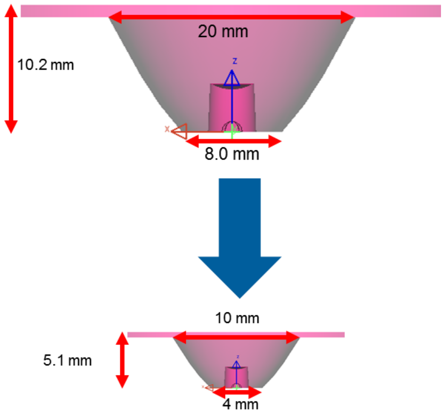
Driver and PCB technology for routing and addressing of individual pixels

Why high-luminance LEDs?

Luminance L_v= d²ϕ / (dS dΩ cos θ)
Luminous flux from a given **source area** within a given **solid angle**



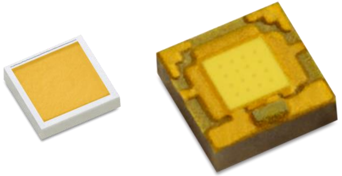
More light delivered on target, energy savings
(even with lower source efficacy)

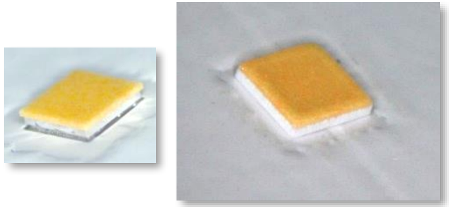


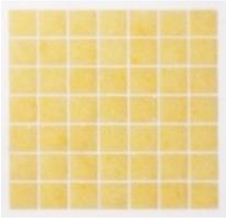
Volume reduction, cost savings

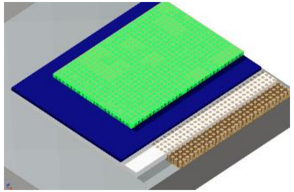
Mid power	L_v ~ 15 cd/mm²
High power (with dome)	L_v ~ 45 cd/mm²
High luminance (without dome)	L_v ~ 100 cd/mm²

High-luminance LEDs for digital light sources









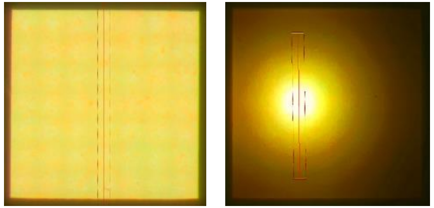
	Discrete HL LED Package size > LES size	**Discrete HL LED** Package size ~ LES size	**Segmented HL LED** on TSV submount	**Segmented HL LED** on CMOS submount
Optics	Distributed	Distributed or single	Single	Single
Pixel size	~ 1 mm^2	~ 1 mm^2	~ 0.1 mm^2	~ 0.01 mm^2
Pixel count	-	Limited by routing	~ 49	10,000 +

Segmented HL LED technology addresses dense packing and routing challenges for dynamic lighting applications

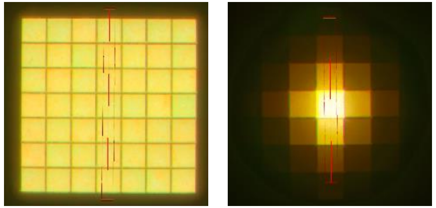
Phosphor integration and spectral tuning

Phosphor integration

- Silicone matrix phosphor integration process
- Optional segmentation for better pixel definition



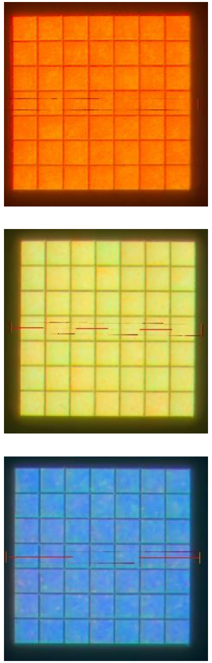
Continuous phosphor film

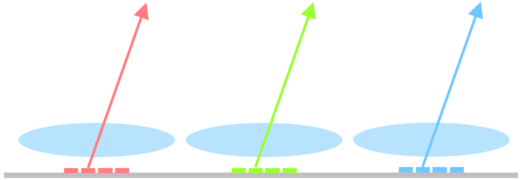


Segmented phosphor film

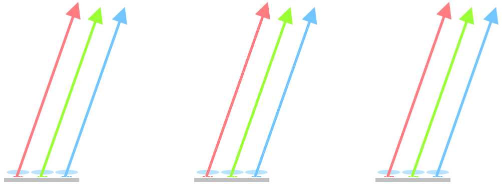
Color / spectral tuning

- Color mixing at source level not practical with projection optics
- Mix colors in the far field, but beware of artefacts





Place primaries close together to minimize visible color separation



Use multiple primary clusters to soften shadows

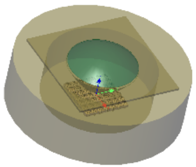
Image projection optics ≠ illumination optics

Image projection lens

- Complex lens system
- **Refractive optics**
- **Image-forming**
- Low optical efficiency

Illumination lens

- **Single lens**
- TIR / reflector optics
- Non-image-forming
- **High optical efficiency**



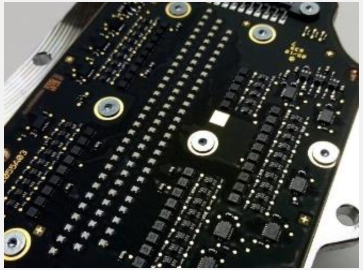
Illumination projection lens

"Good enough" imaging with maximum optical efficiency

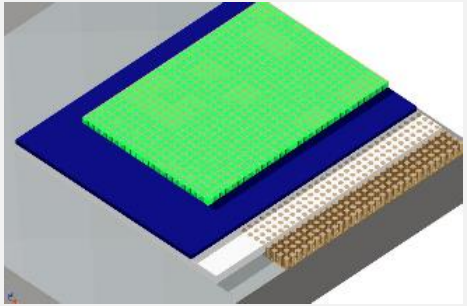
How to control tens or hundreds of pixels?

Automotive

~100 pixels: discrete driver implementation



~10,000 pixels: CMOS backplane integration

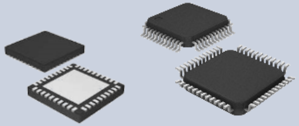


Illumination

~10-100 pixels: **discrete driver implementation**

Requirements
- High channel count
- High efficiency
- ~50-200 mA drive current per pixel depending on pixel size
- Dimming (PWM, analog, deep dimming)
- Digital control (SPI, I2C)

Leverage IC technology developed for local dimming / full array backlight



Digital light sources for dynamic indoor spaces

Many variables

People (# and position)

Activities

Space layout

Time of day

Benefits of digital light source

- Optimized visual performance for every situation
- Optimized melanopic light dosage throughout the day
- Energy savings

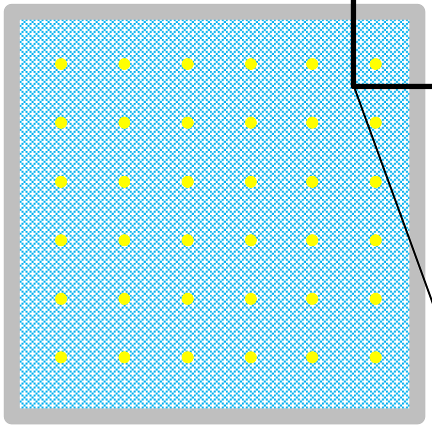
Full-function dynamic light source

Tuning over wide range of beam angles and spectra

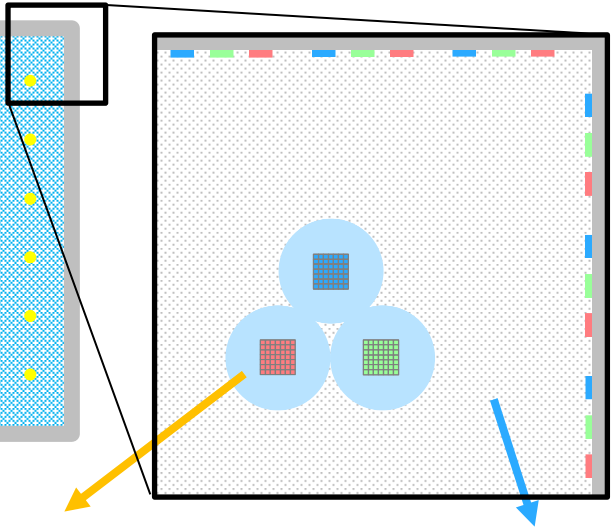
“Spatially Adaptive Tunable Lighting Control System with Expanded Wellness and Energy Saving Benefits”

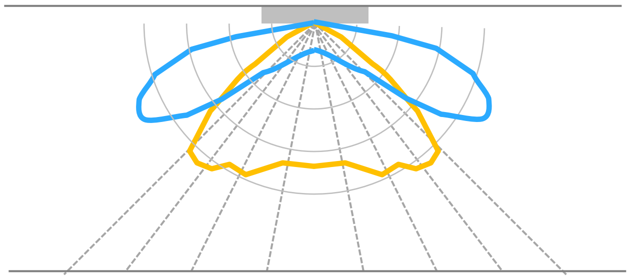
DE-EE0009167

Rensselaer Polytechnic Institute, Lumileds, HKS



2’ x 2’ troffer





Projection optics for low/medium angles

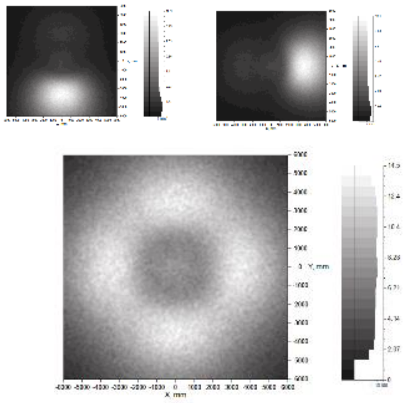
- Precise beam control with pixelated source
- Stitch light engines for full coverage of horizontal surface (desk/floor)

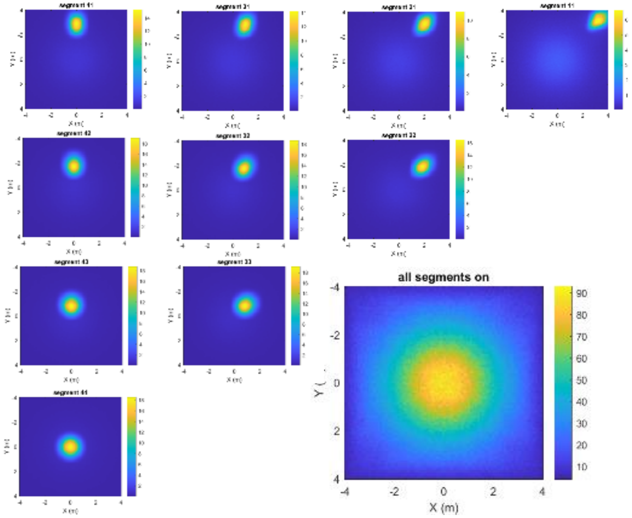
Light guide optics for high angles

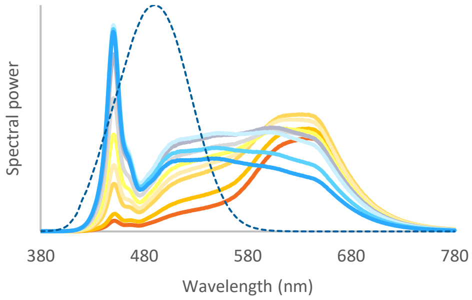
- Complement to cover full beam angle range
- Enable vertical illuminance
- Mitigate glare from projection optics

Both sections fully CCT tunable

Target specifications





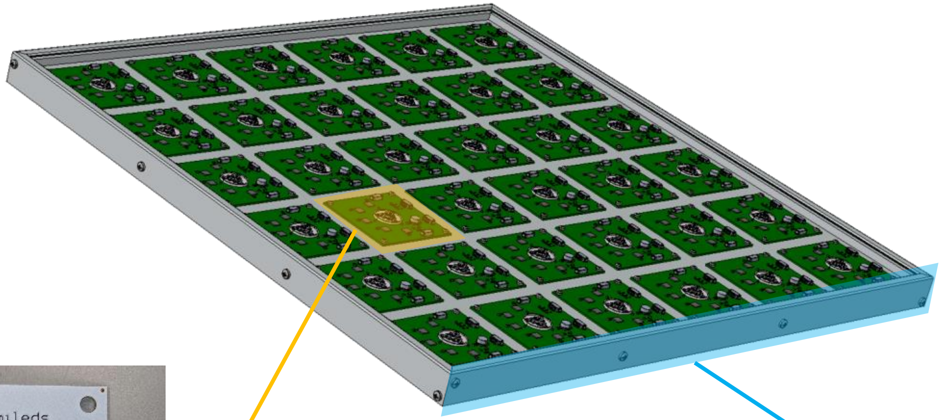


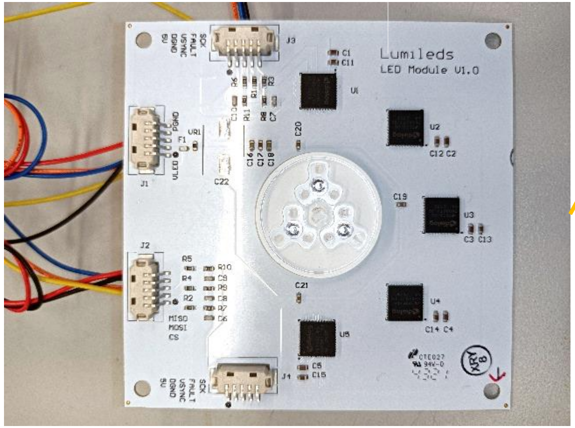
Light guide section	
Beam angle peak to peak	128°
Beam angle FWHM	152°
Number of segments	4
Nominal flux per segment	1400 lm

Projection section	
Beam angle FWHM	100°
Number of segments	49
Nominal flux per segment	500 lm

Spectrum (both sections)	
CCT range	2200-10000K
CRI (min 2700-6500K)	Ra>90, R9>50
Melanopic ratio (MDER)	0.35-1.12
Melanopic ratio (MEER)	0.38-1.24

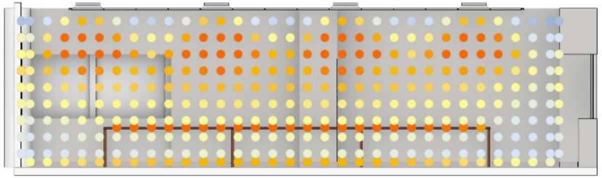
Light engine prototyping



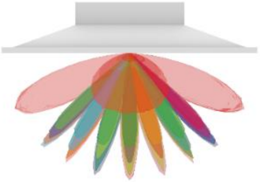


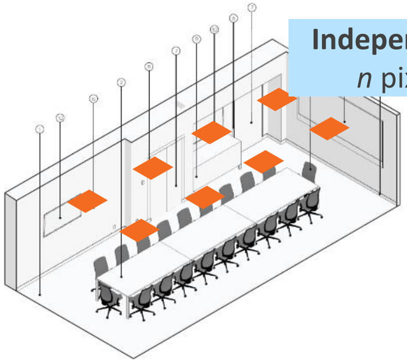
Optimizing for a target luminance distribution

Constraints
m illuminance sample points, *m* ~ *n*



Independent variables
n pixels, *n* = 424





53 pixels per fixture

8 fixtures

Linear system description

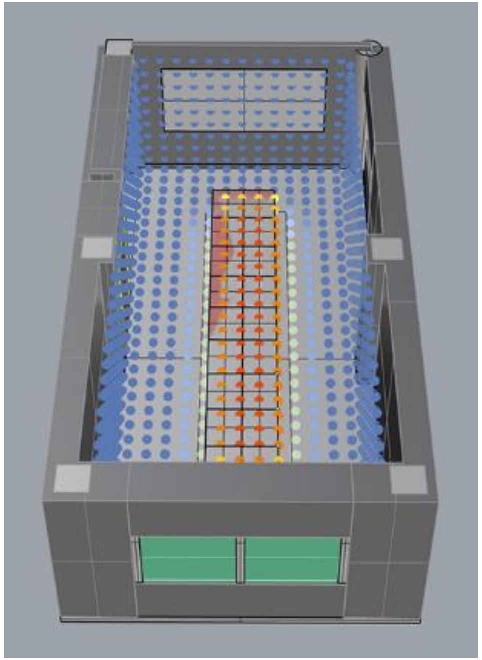
$$\begin{bmatrix} E_1 \\ \vdots \\ E_m \end{bmatrix} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix} \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix}$$

Illuminance values

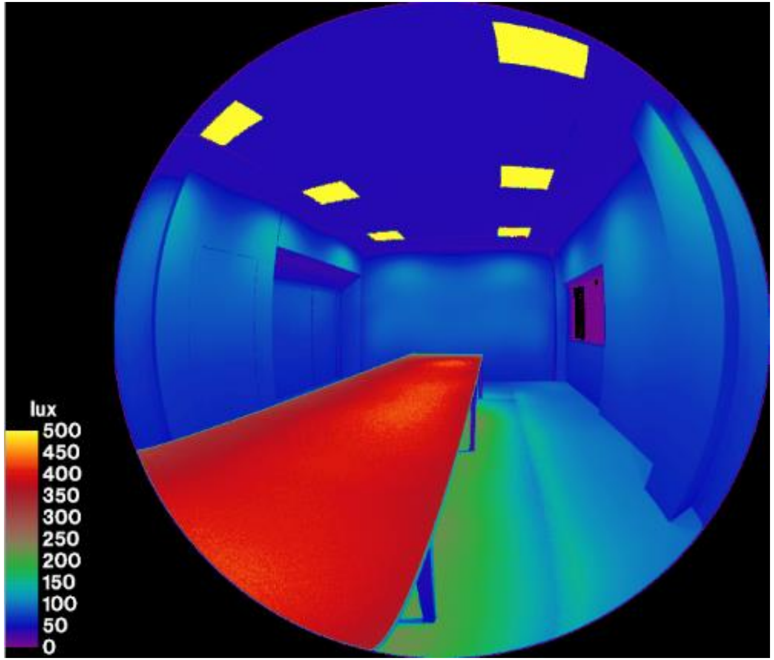
Illuminance at sample point 1..*m* due to pixel 1..*n*

Pixel output values

Example: uniform illuminance on table surface

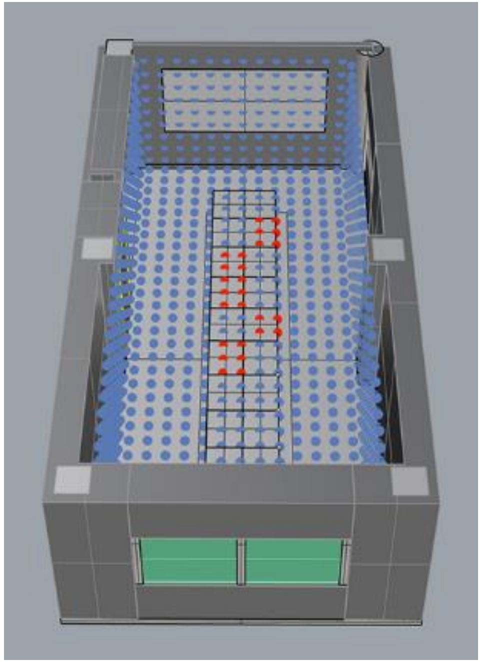


Target

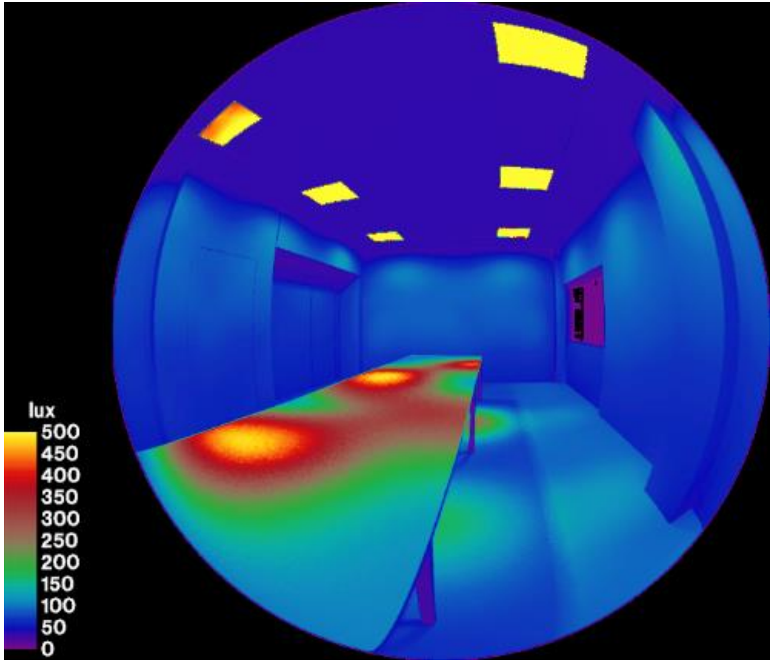


Radiance simulation

Example: spotlight on table at selected seats

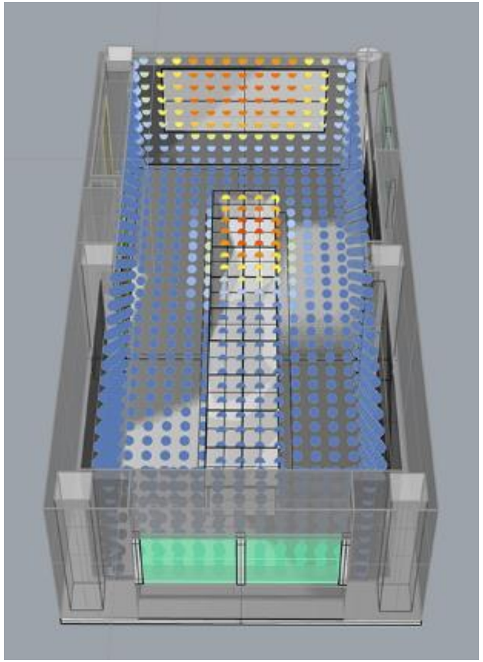


Target

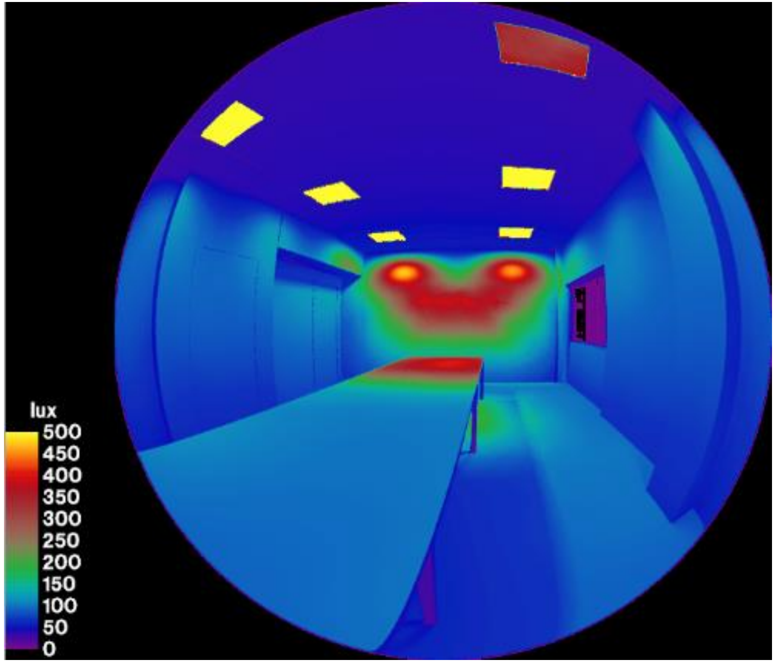


Radiance simulation

Example: whiteboard and table



Target



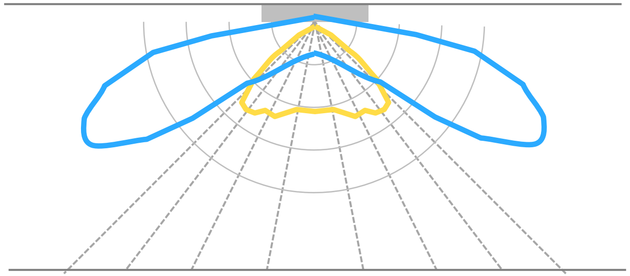
Radiance simulation

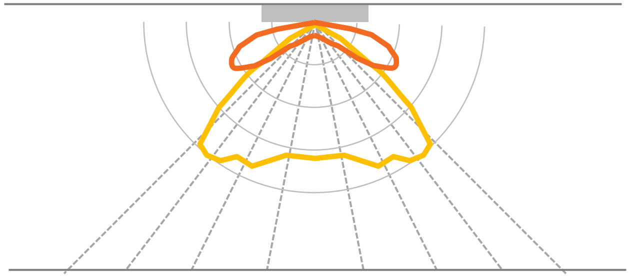
Meeting melanopic EDI targets efficiently without glare

Recommended MEDI levels from IWCNP 2
> 250 lx daytime
< 10 lx evening
< 1 lx nighttime (sleep)

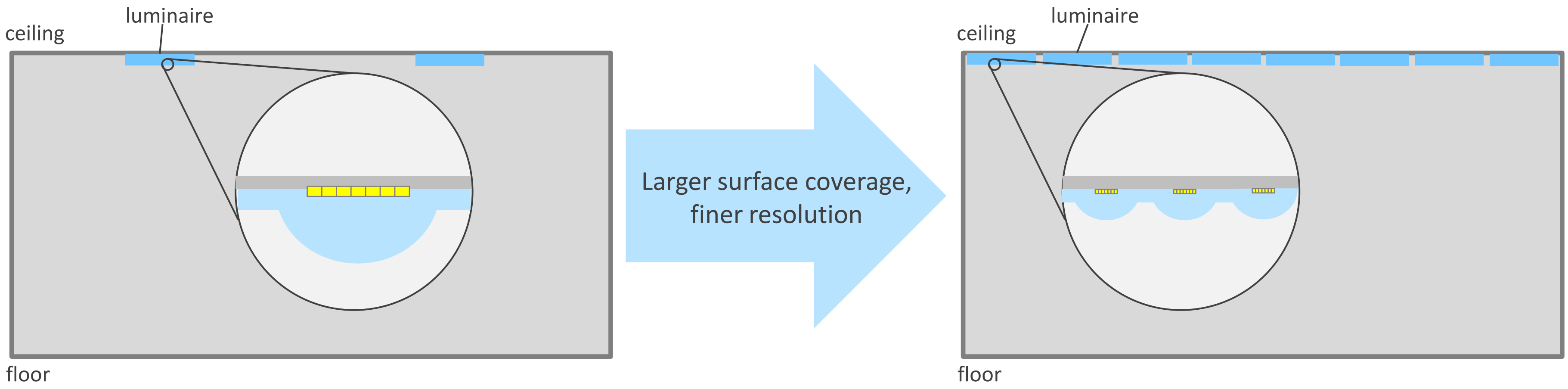
Light distribution for high ocular MEDI
Large overhead luminous surfaces in direct view

Light distribution for low ocular MEDI
Mostly indirect light, lighting only areas of interest

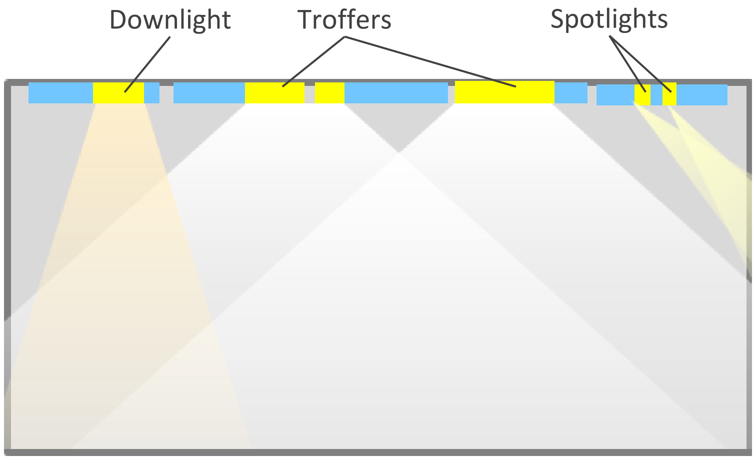




Digital ceilings: send light not only <u>to</u> anywhere, but also <u>from</u> anywhere



Example: Virtual luminaires

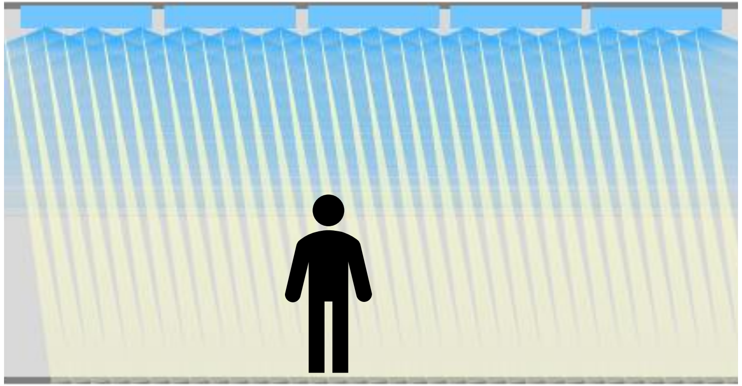


Fully digital design and commissioning approaches

- Upload custom design
- Point-and-click
- Sensors/controls-based

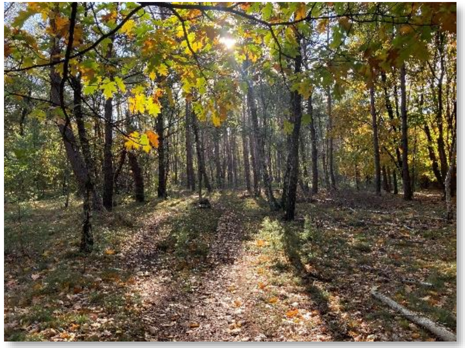
…not constrained to traditional fixture form factors and intensity distributions

Example: Artificial skylights



Direct view for person looking up at skylight

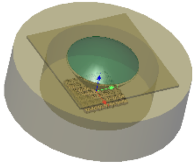
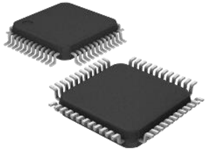
- Diffuse skylight + directional sunlight (both color tunable)
- Sun moves along with observer (infinite distance perception)
- Trace solar path across sky
- Simulate sky scenes <u>including</u> light distributions (not just a display)



Summary

Digital light source technology

Essential technology building blocks are available now and will further improve over time

Digital light source applications

Initial applications based on conventional lighting performance criteria

- Energy consumption
- Beam definition
- Illuminance uniformity
- Glare control




Advanced applications with value beyond traditional scope of lighting

- Human health and wellbeing
- Building space flexibility
- Aesthetics / artistic design
- Streamlined supply chain
- Accelerated building construction

How will you use digital light sources in your next product or lighting design?

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