A Physiologically-Based Framework for the Simulation of Skin Tanning Dynamics

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Outline

- Introduction
- Photobiological Background
- Framework Description
- Results and Discussion
- Conclusion

Introduction

- Tanning is one of the most striking appearance changes in humans skin

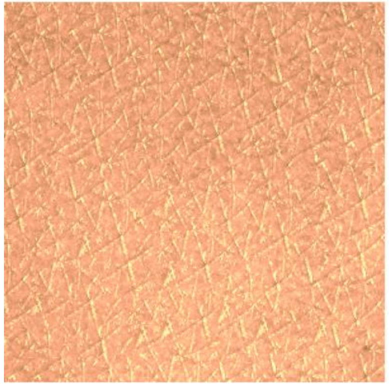
- How do we simulate this non-linear phenomenon?
    - When does a tan reach a steady state plateau in response to ultraviolet radiation (UVR) exposure?
    - For how long does the plateau last?
    - How does the exposure dose affect the timing and duration of a tan already in progress?
    - How does it affect a tan that is already fading?

Introduction: Contribution

- A novel comprehensive framework for the physiologically-based simulation and visualization of time-dependent skin appearance changes resulting from tanning elicited by UVR exposure

- We are **not** presenting a new skin appearance model

- One can employ any predictive model in the visualization of the framework results



Specimen 1
(BioSpec Model)

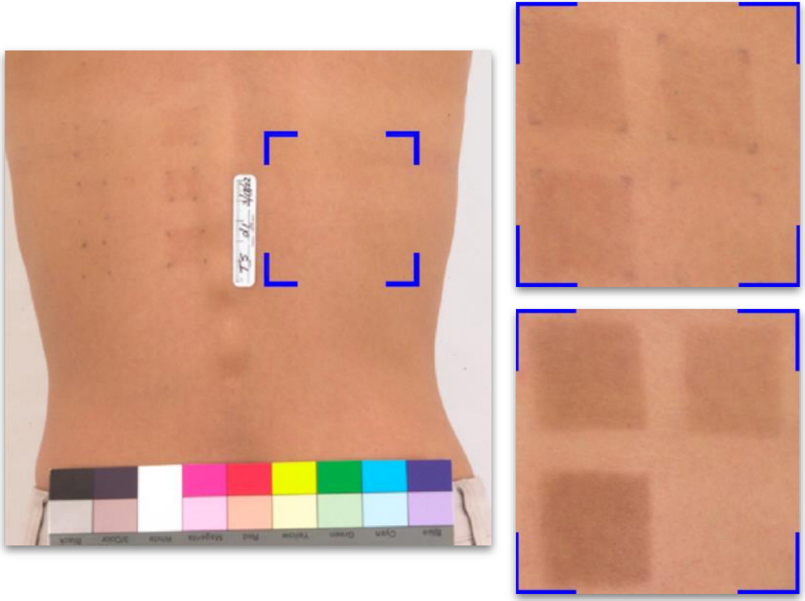
Specimen 2
(HyLIoS Model)

Introduction: Related work

Simulation of skin appearance changes:

- Folds and wrinkles
  - [Magnenat-Thalmann et al. 2002]
- Anemia and cyanosis
  - [Baranoski et al. 2015 and 2017]
- Pigmentation disorders
  - [Barros and Walter 2016]

- Tanning
  - [Thingnes et al. 2009 and 2014]
    Does not account for different UVR sensitivities and skin thickness changes



Courtesy of S. Miller

Introduction: Relevance

- *In silico* investigation of spectrally-dependent photobiological phenomena affecting skin appearance and natural protection over time

- Enhancement of the level of realism of virtual human characters

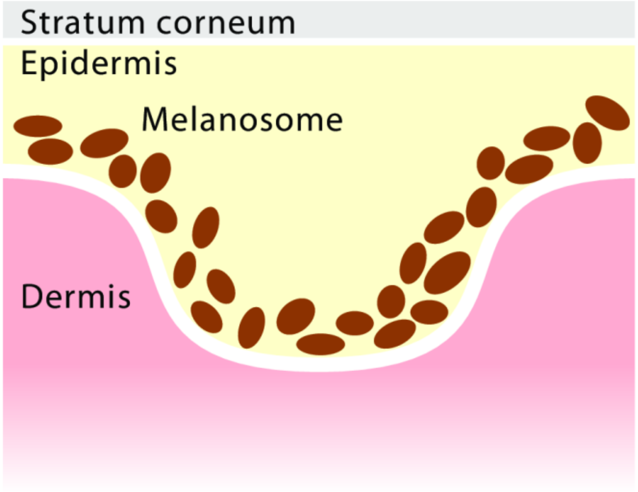
Photobiological Background: Skin Structure

Layers (from top to bottom):

- Stratum corneum
- Epidermis
  - Stratum granulosum
  - Stratum spinosum
  - Stratum basale
- Dermis

Pigment:

- Melanin
  - Contained within melanosomes
    - Produced by melanocytes

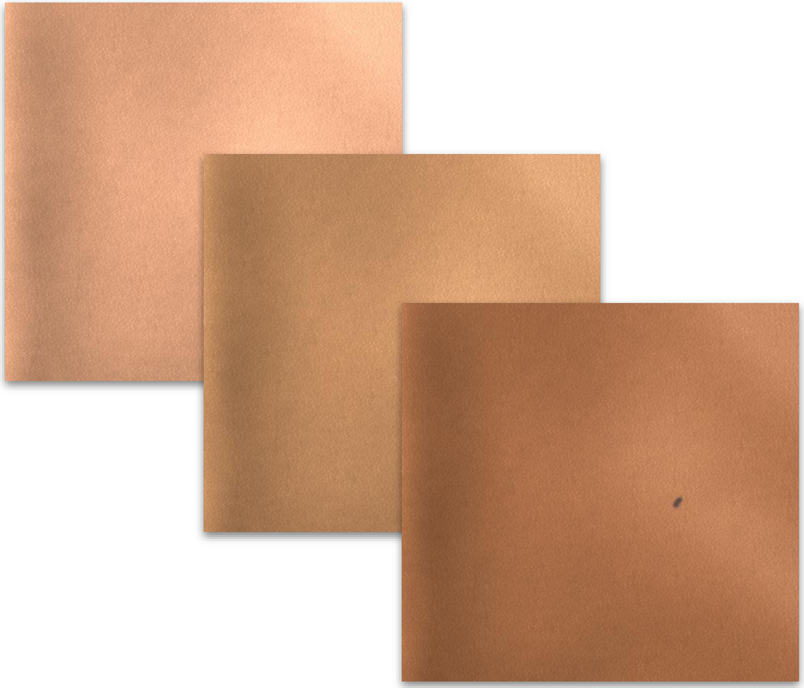


Photobiological Background: Skin Phototype

Fitzpatrick skin phototype (SPT):

- Used to characterize
  - Pigmentation baseline
  - Ability to tan
  - Resistance to sunburn

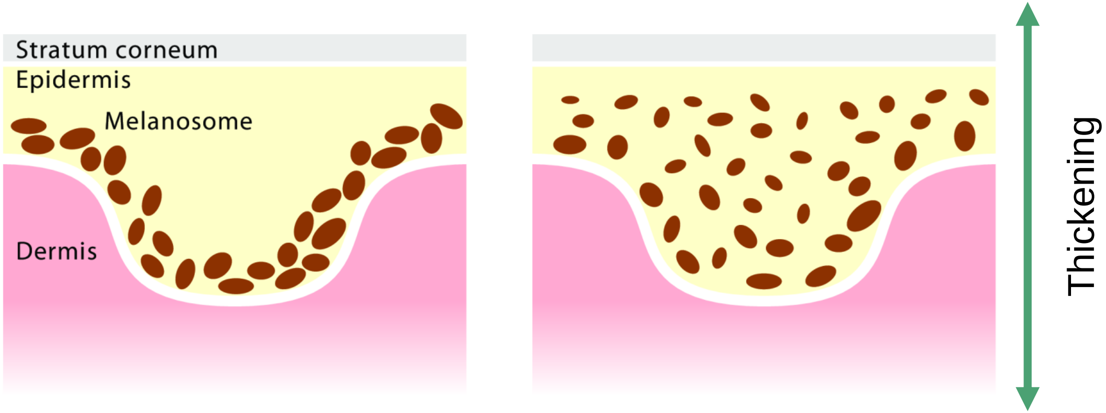
- From lowest to highest:
  - SPT I, II, III, IV, V and VI



Photobiological Background: Tanning Responses

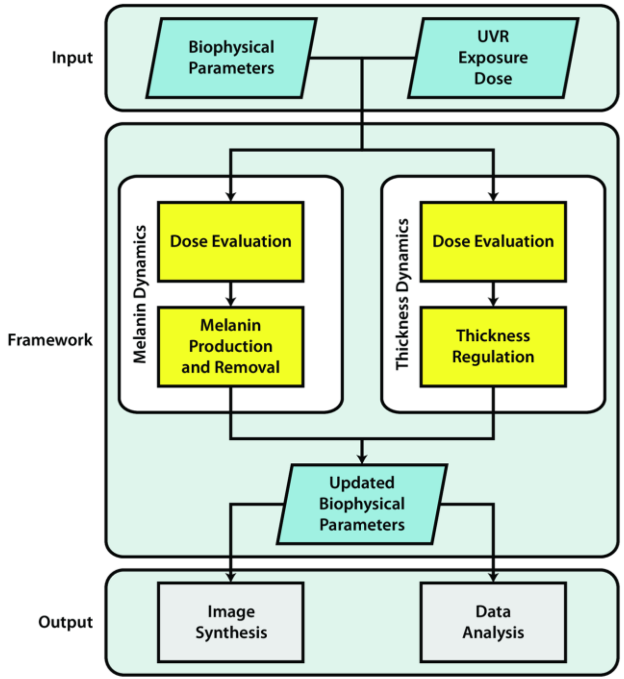
Two primary changes:

- Melanin distribution
- Skin thickening



Framework Description: Overview

- Based on current understanding of skin tanning process
- Input: Skin parameters + UVR dose
- Computation: Melanin + thickness dynamics
- Output: Updated biophysical parameters + appearance attributes

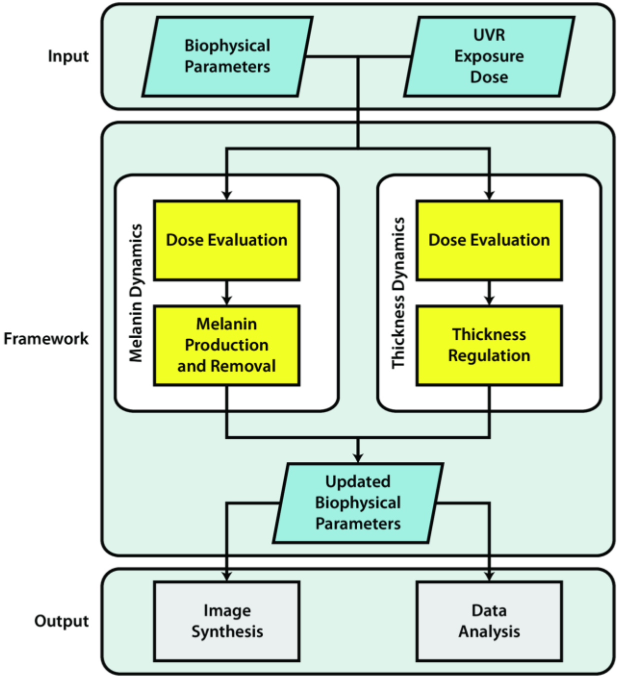


Framework Description: Overview

- A light interaction model is needed for UVR dose evaluation
  - Such a model needs to be predictive in the UV domain

- A light interaction model is also needed for the computation of skin appearance attributes

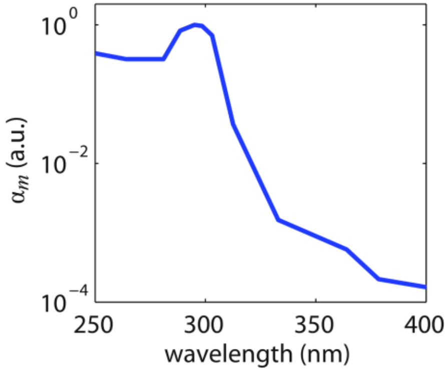
- Selected model: HyLIoS (Chen et al. 2015)



Framework Description: Initiation

When to stimulate **melanin** dynamics:

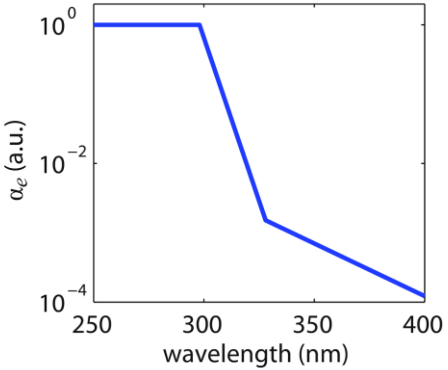
Input dose > Min. **melanogenesis** dose



Weighted by melanogenesis action spectrum and skin absorptance

When to stimulate **thickness** dynamics:

Input dose > Min. **erythema** dose

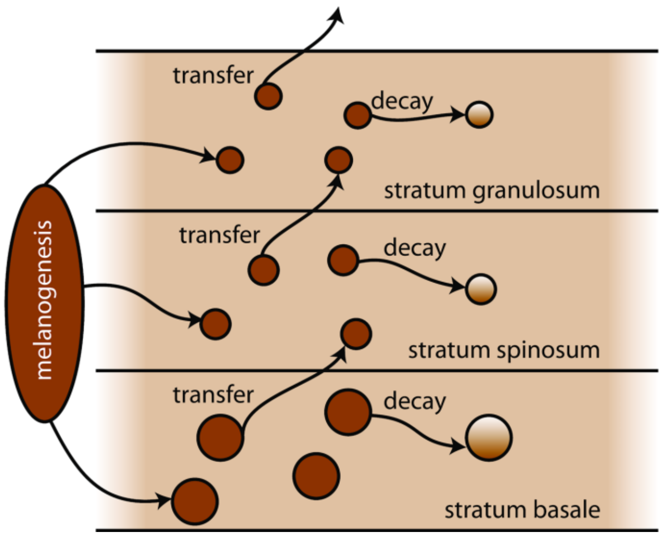


Weighted by erythema action spectrum and skin absorptance

Framework Description: Melanin Dynamics

- Increase in melanin content in a layer
  - Produced internally within the layer
  - Transferred from another layer (below)

- Decrease in melanin content in a layer
  - Natural decay
  - Transferred to another layer (above)

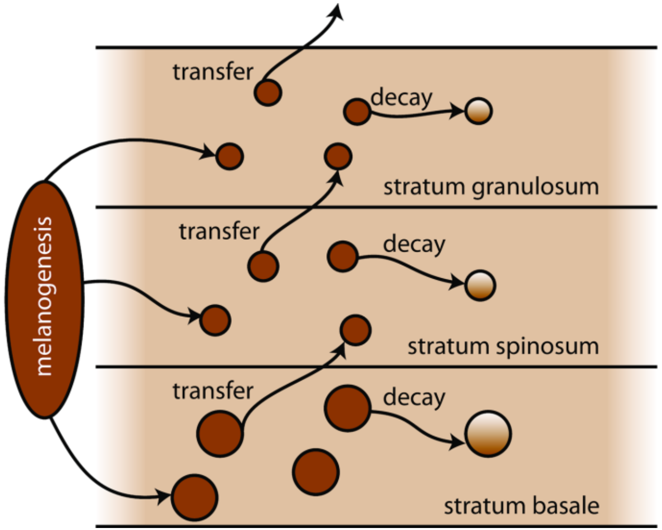


Framework Description: Melanin Dynamics

- Input dose is used to modulate factors that increase and decrease melanin content
  - Sufficient input UV dose
  - Triggers production of signal substance
  - Triggers melanin production and transfer

$$
\begin{aligned}
m(t) = p(t) \\
+ m(t-1) \cdot \delta \cdot \tau(t) \\
+ m_{-1}(t-1) \cdot \tau_{-1}(t)
\end{aligned}
$$

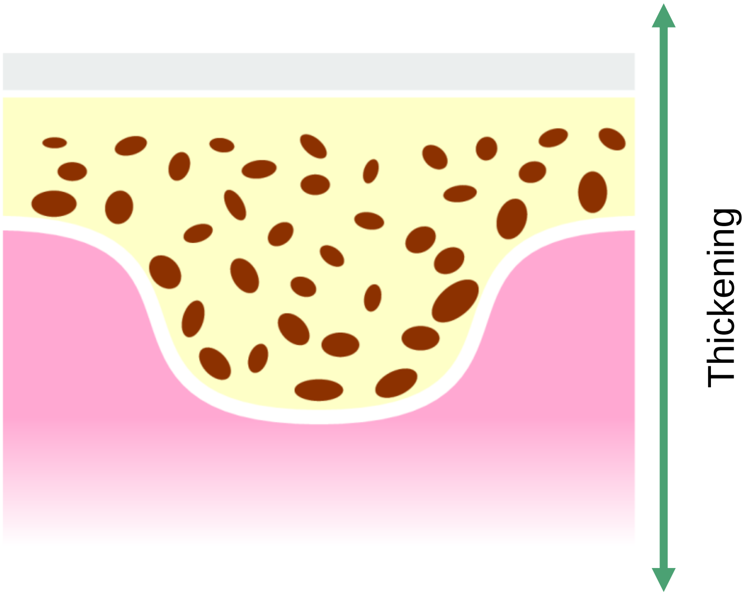
- Final output
  - Relative change in layer-specific and overall melanin content



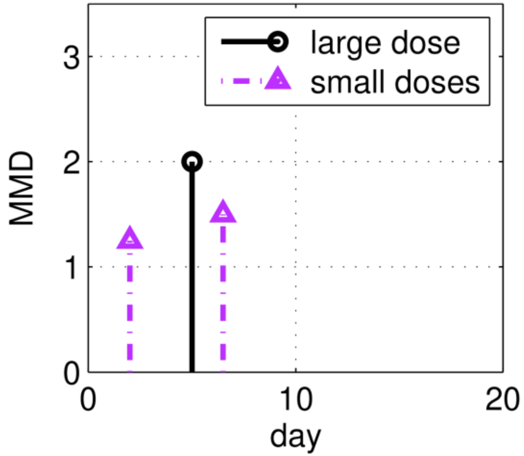
Framework Description: Thickness Dynamics

- Input dose is used to modulate factors that increase and decrease skin thickness
  - Similar algorithm as melanin dynamics

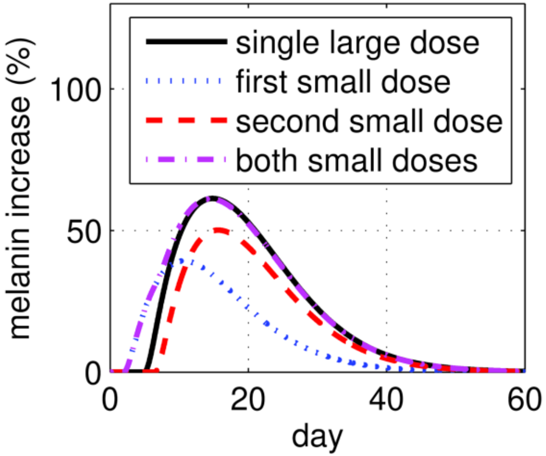
- Final output
  - Relative change in layer-specific thickness



Results and Discussion: Photoaddition

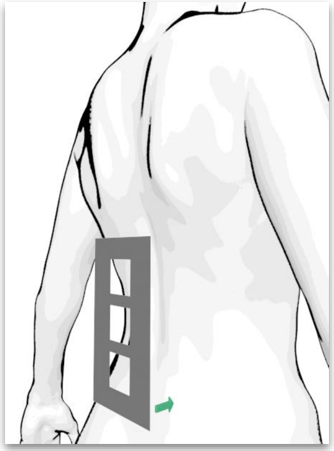


Input doses

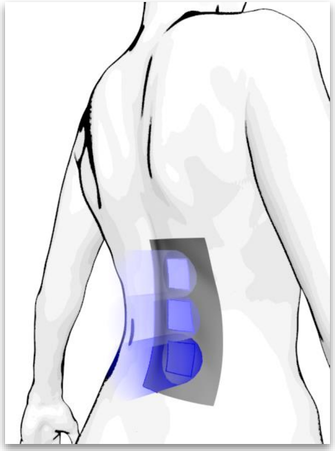


Melanin content

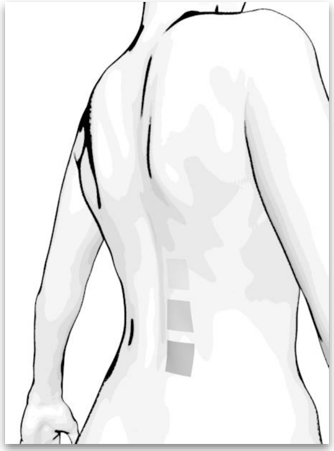
Results and Discussion: Simulated Experiment



Apply template

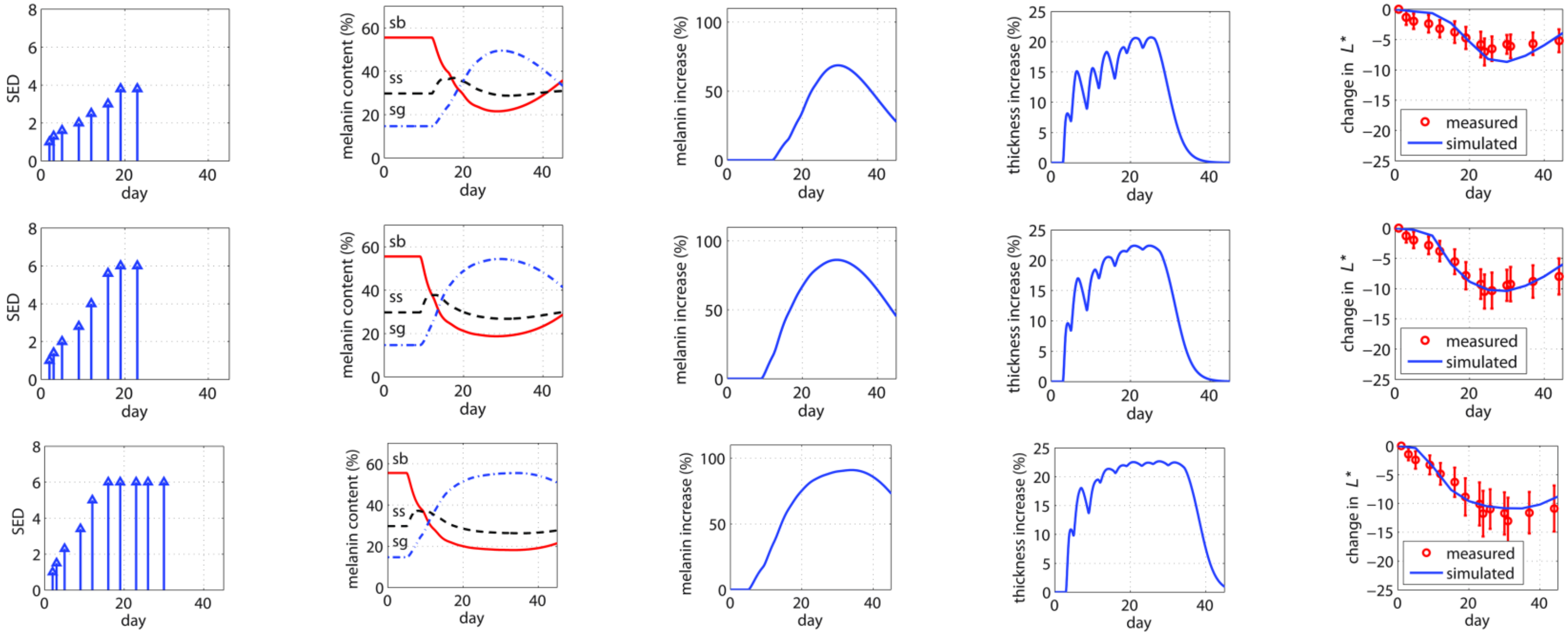


Expose to UVR



Record changes

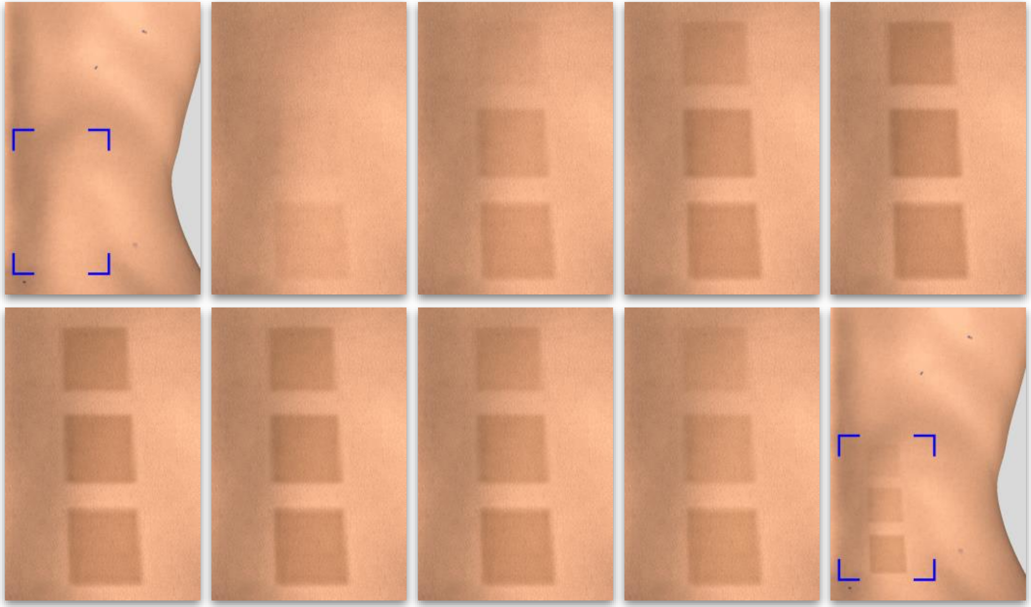
Results and Discussion: Different Exposures



Input doses | Melanin content (relative) | Melanin content (total) | Thickness | Lightness

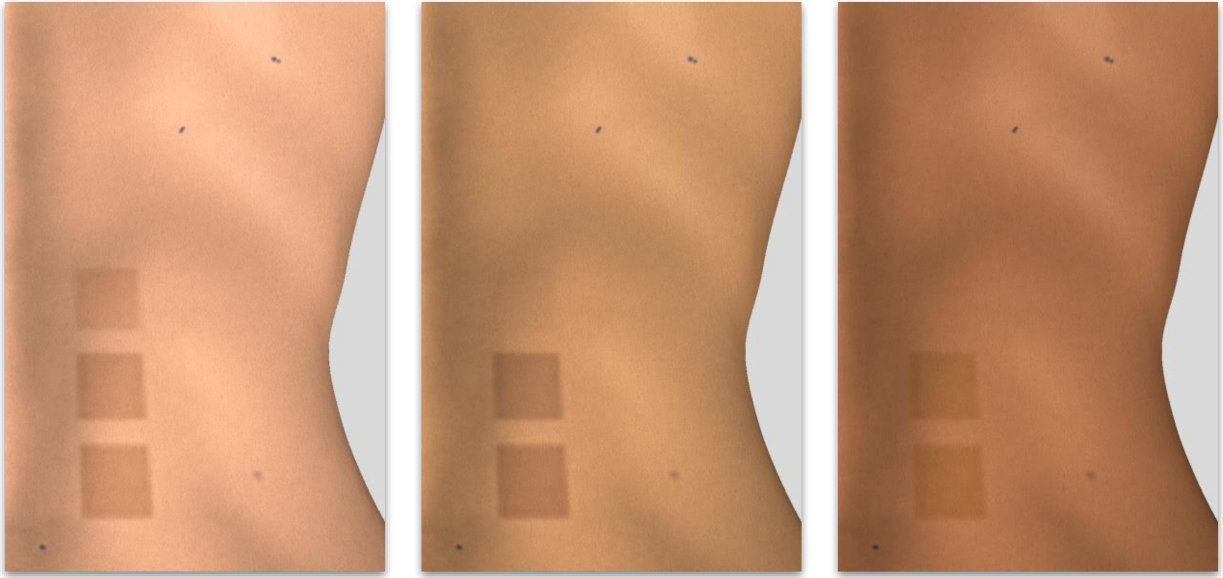
Measured data from Miller et al. 2012

Results and Discussion: Visualization



Rendering of appearance transition (using computer graphics techniques)

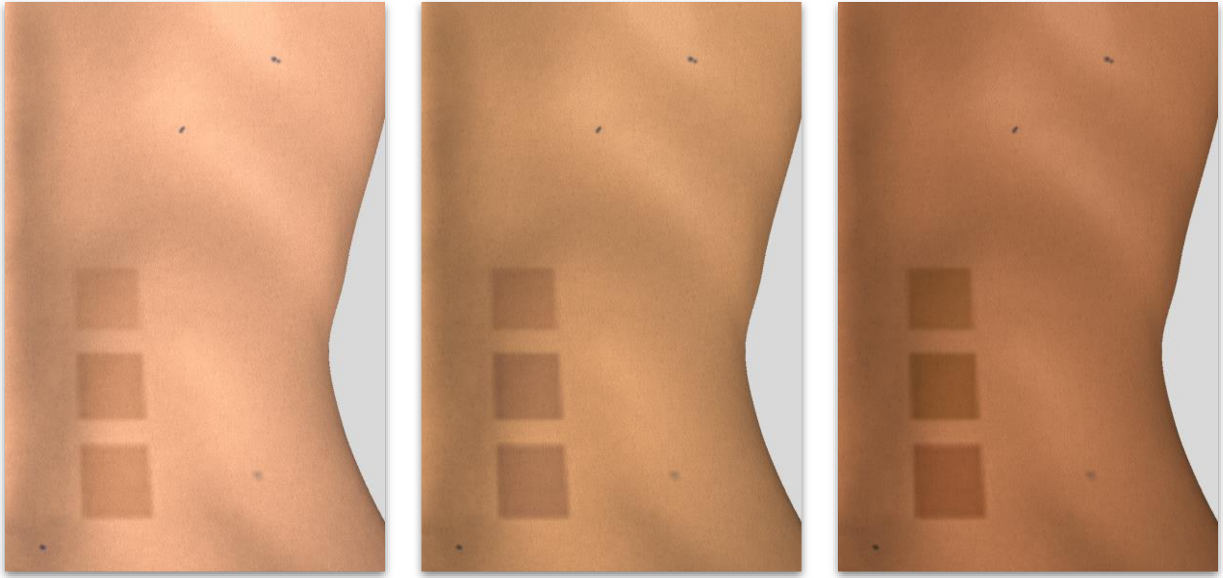
Results and Discussion: Different Skin Phototypes



Higher UVR sensitivity of individuals with low SPT

Trend consistent with experimental observations (e.g., Ravnbak et al. 2008)

Results and Discussion: Different UV Doses

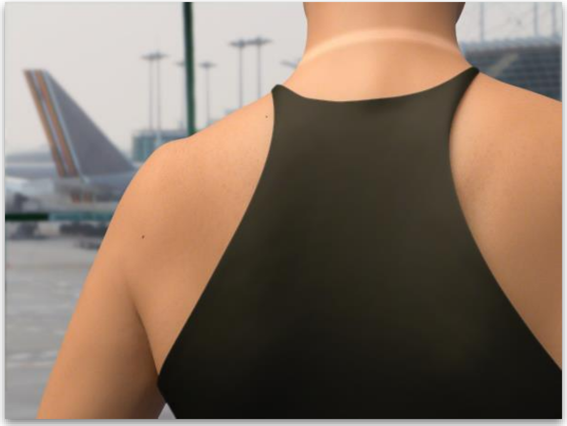


Higher tanning ability of individuals with high SPT

Trend consistent with experimental observations (e.g., Miller et al. 2012)

Results and Discussion

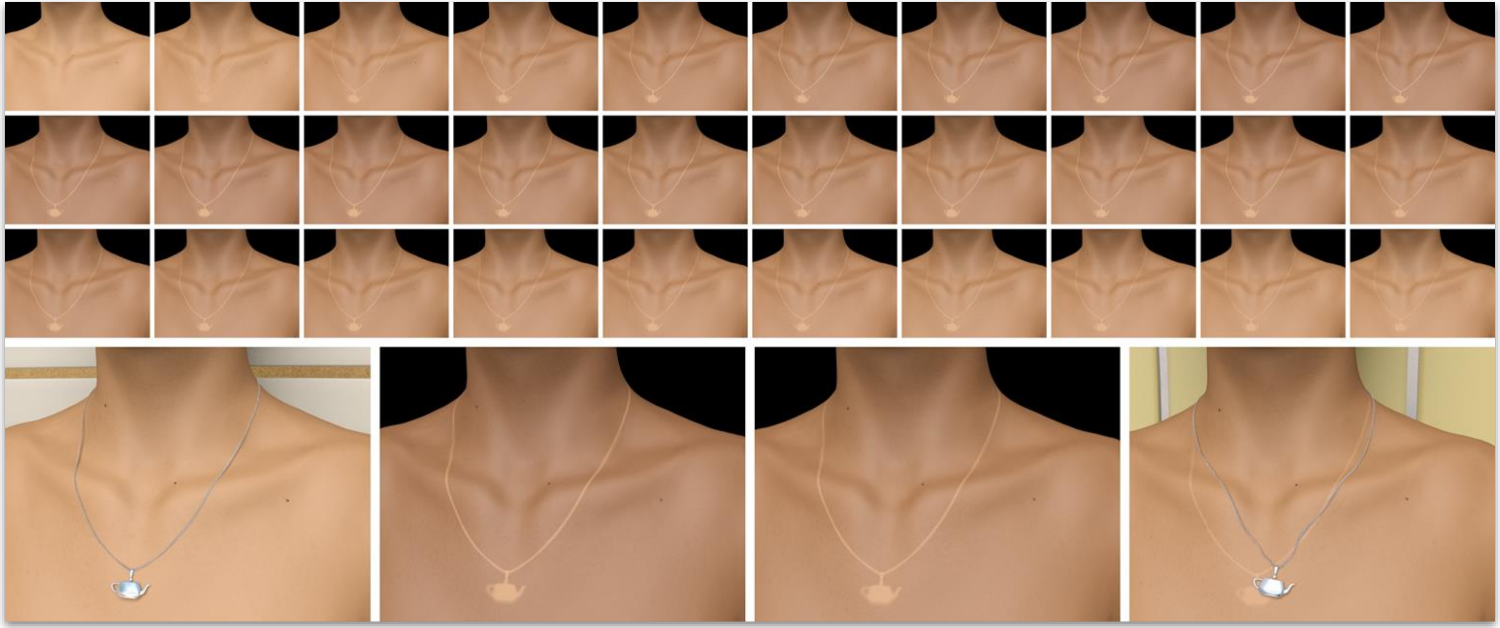
During exposure



Few days after exposure

Couple weeks after exposure

Results and Discussion: Full Animation



Non-linear behavior consistent with experimental observations (e.g., Ravnbak et al. 2008)

Small frames: every 1 day

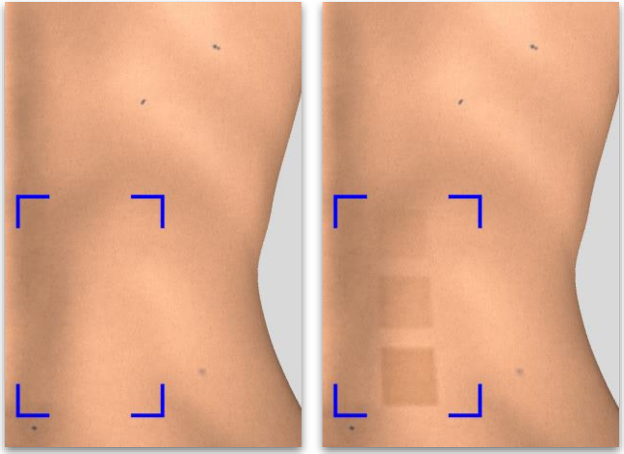
Large frames: every 10 days

< 1s to compute 1 year of data

Conclusion

- We present a novel comprehensive framework for the physiologically-based simulation and visualization of time-dependent skin appearance changes resulting from tanning elicited by UVR exposure

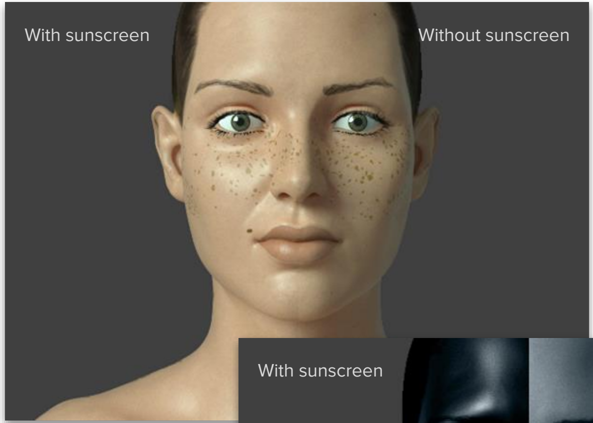
- It establishes causal relationship between virtual environment and skin appearance



Conclusion

- It supports interdisciplinary research involving *in silico* testing of protective products (e.g., sunscreens)

- It can be used to promote public awareness regarding the harmful effects of UVR



Visible

Ultraviolet

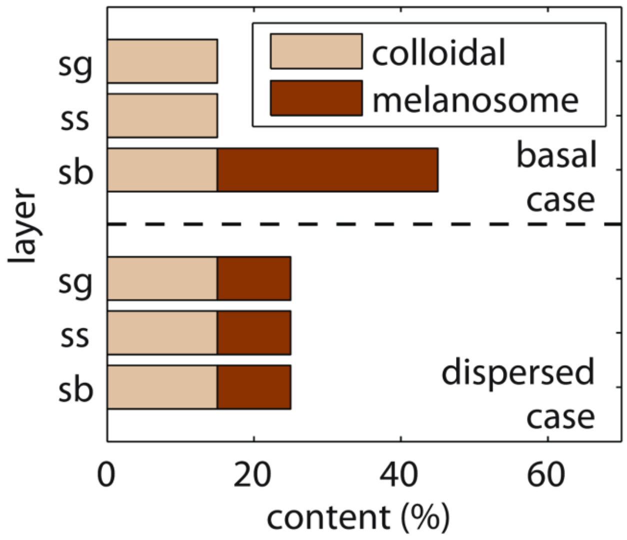
Thank You!

- Group page
  - **http://www.npsg.uwaterloo.ca**

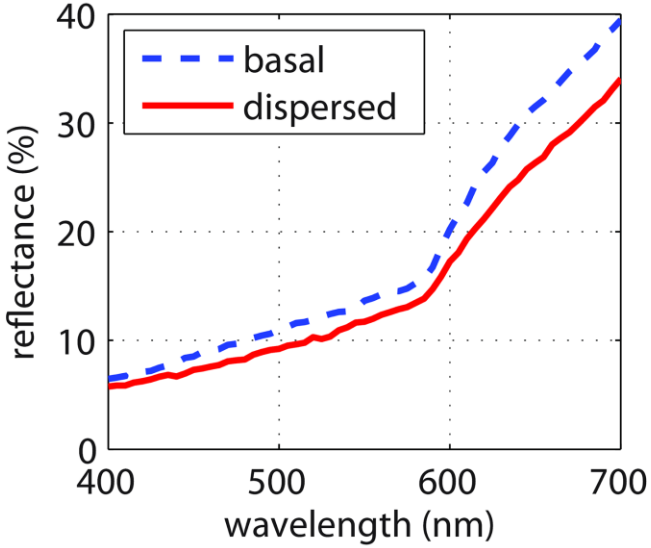
- Videos:
  - **http://www.youtube.com/UWNPSG**

Supplementary Material

Framework Description: Melanin Dynamics



Different melanin distribution

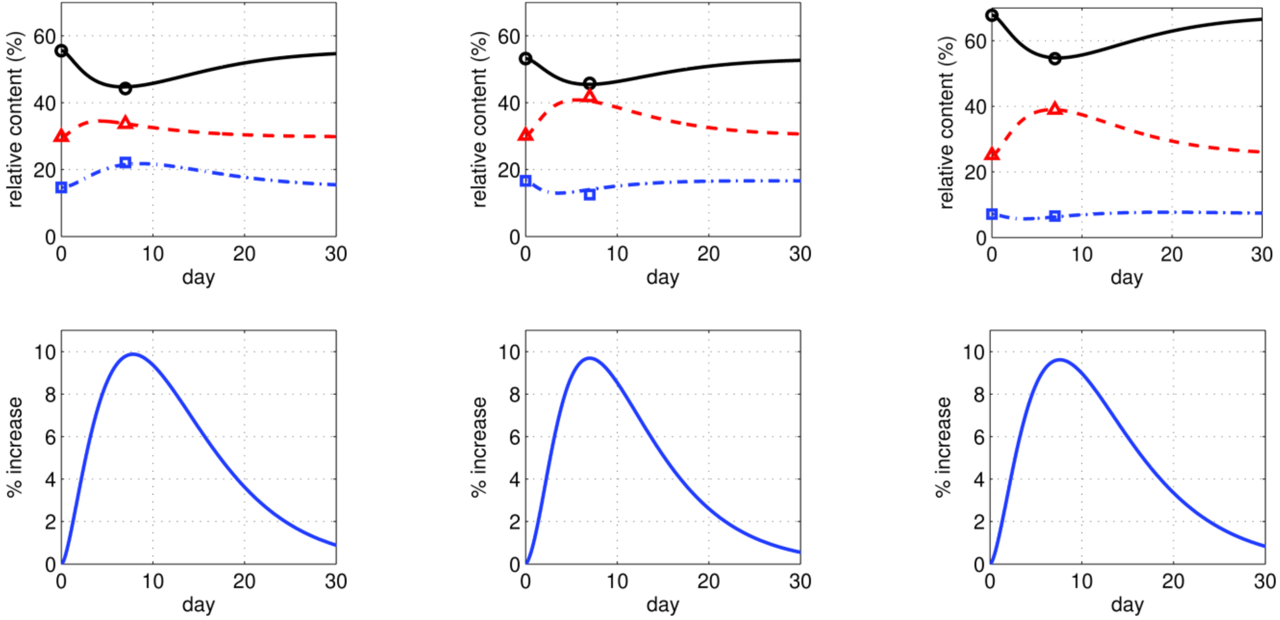


Different skin reflectance

Deriving Tanning Specification Data

Pigmentation distribution change

Pigmentation overall change



Lightly pigmented

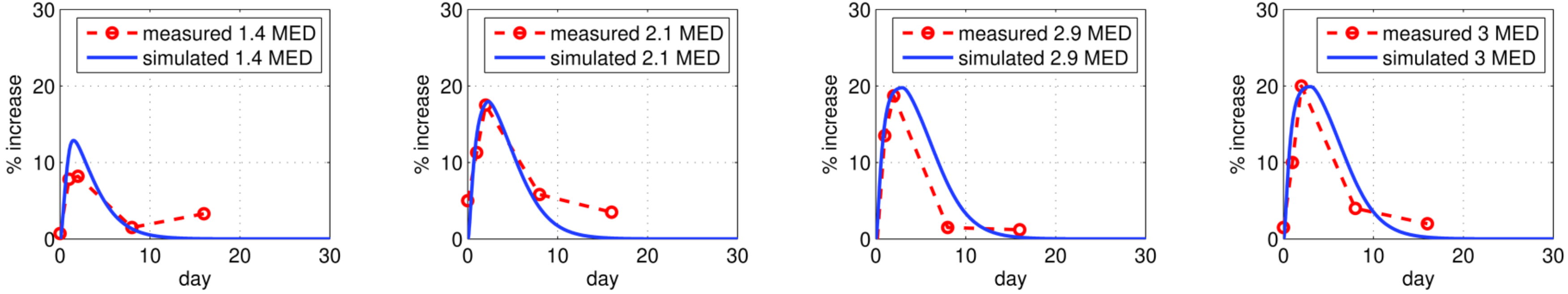
Moderately pigmented

Darkly pigmented

Measured data from Tadokoro et al. 2005

Deriving Tanning Specification Data

Thickness change for different MED



Measured data from Lopez et al. 2004

Swatches Rendered Using BioSpec

Hill Equation

- Used to produce a sigmoidal curve
  - s: amount of signal substance
  - k: cooperativity (binding ability)
  - w: dissociation (threshold)

- Equation originally used to describe oxygen binding to hemoglobin

- S. Goutelle, M. Maurin, F. Rougier, X. Barbaut, L. Bourguignon, M. Ducher, and P. Maire, "**The Hill equation: a review of its capabilities in pharmacological modelling**," Fund. Clin. Dermatol., vol. 22, pp. 633–648, 2008.

$$M = \frac{s^k}{s^k + w^k}$$

Full Citations: Measured Data

- S.A. Miller, S.G. Coelho, S.W. Miller, Y. Yamaguchi, V.J. Hearing, and J.Z. Beer, "**Evidence for a new paradigm for ultraviolet exposure: a universal schedule that is skin phototype independent**," Photodermatol. Photoimunol. Photomed., vol. 28, no. 4, pp. 187–195, 2012.

- M.H. Ravnbak, P.A. Philipsen, S.R. Wiegell, and H.C. Wulf, "**Skin pigmentation kinetics after UVB exposure**.," Acta Derm. Venereol., vol. 88, no. 3, pp. 223–228, 2008.

- T. Tadokoro, Y. Yamaguchi, J. Batzer, S.G. Coelho, B.Z. Zmudzka, S.A. Miller, R. Wolber, J.Z. Beer, and V.J. Hearing, "**Mechanisms of skin tanning in different racial/ethnic groups in response to ultraviolet radiation**," J. Investig. Dermatol., vol. 124, no. 6, pp. 1326–1332, 2005.

- H. Lopez, Z.J. Beer, S.A. Miller, and B.Z. Zmudzka, "**Ultrasound measurements of skin thickness after UV exposure: a feasibility study**," J. of Photochem. Photobiol. B, vol. 73, no. 3, pp. 123–132, 2004.

Full Citations: Related Works

- N. Magnenat-Thalmann, P. Kalra, J.L. L´evˆeque, R. Bazin, D. Batisse, and B. Querleux, “**A computational skin model: fold and wrinkle formation**,” IEEE Trans. Inf. Technol. B., vol. 6, no. 4, pp. 317–323, 2002.

- J. Thingnes, L. Oyehaug, E. Hovig, and S. Omholt, “**The mathematics of tanning**,” BMC Syst. Biol., vol. 3, no. 1, pp. 60, 2009.

- J. Thingnes, L. Oyehaug, and E. Hovig, “**Mathematical and biological processes of skin pigmentation**,” in Computational Biosphysics of the Skin, B. Querleux, Ed., pp. 3–24. Pan Stanford Pub., Singapore, 2014.

- G.V.G. Baranoski, A. Dey, and T. F. Chen, “**Assessing the sensitivity of human skin hyperspectral responses to increasing anemia severity levels**,” J. Biomed. Opt., vol. 20, no. 9, pp. 095002:1–14, 2015.

- G.V.G Baranoski, S.R. Van Leeuwen, and T.F. Chen, “**Elucidating the biophysical processes responsible for the chromatic attributes of peripheral cyanosis**,” in 39th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Jeju, South Korea, August 2017, pp. 90–95.

- R.S. Barros and M. Walter, “**Synthesis of human skin pigmentation disorders**,” Comput. Graph. Forum, vol. 36, no. 1, pp. 330–344, 2016.

Full Citations: Appearance Models

- T.F. Chen, G.V.G. Baranoski, B.W. Kimmel, and E. Miranda, "**Hyperspectral modeling of skin appearance**," ACM T. Graphic., vol. 34, no. 3, pp. 31:1–31:14, 2015.

- A. Krishnaswamy and G.V.G. Baranoski, "**A biophysically-based spectral model of light interaction with human skin**," Comput. Graph. Forum, vol. 23, no. 3, pp. 331–340, 2004.