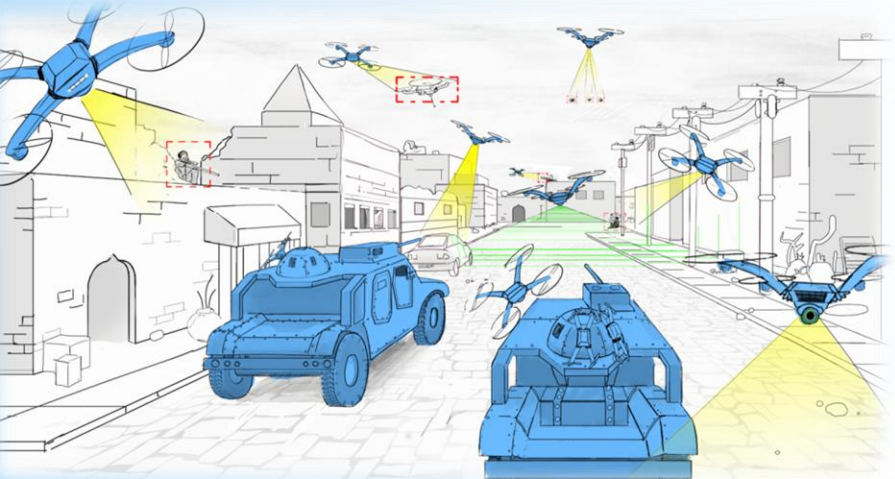
SANTOSHUMAN®

Predictive Human Models and the Third Offset

Optimization-Based Coupled Human Systems Integration

What is it?



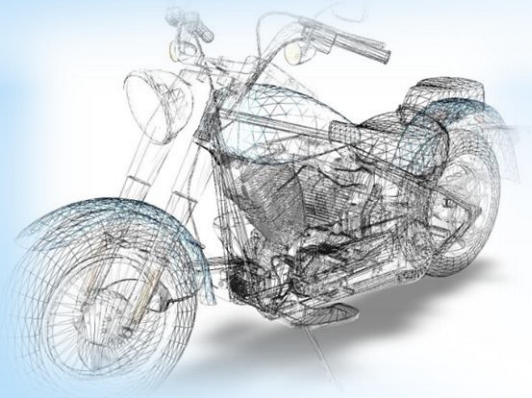

“If you don’t have a competitive advantage, don’t compete.”
JACK WELCH
legendary CEO

Key Points:

1) Autonomous deep learning machines and systems for intelligence
2) Human-machine collaboration for improved decision-making
3) Assisted-human operations
4) Advanced manned and unmanned combat teaming
5) Network-enabled semi-autonomous and autonomous weapons, hardened for EW

The New Big 5 (for the latest Army Operating concept):

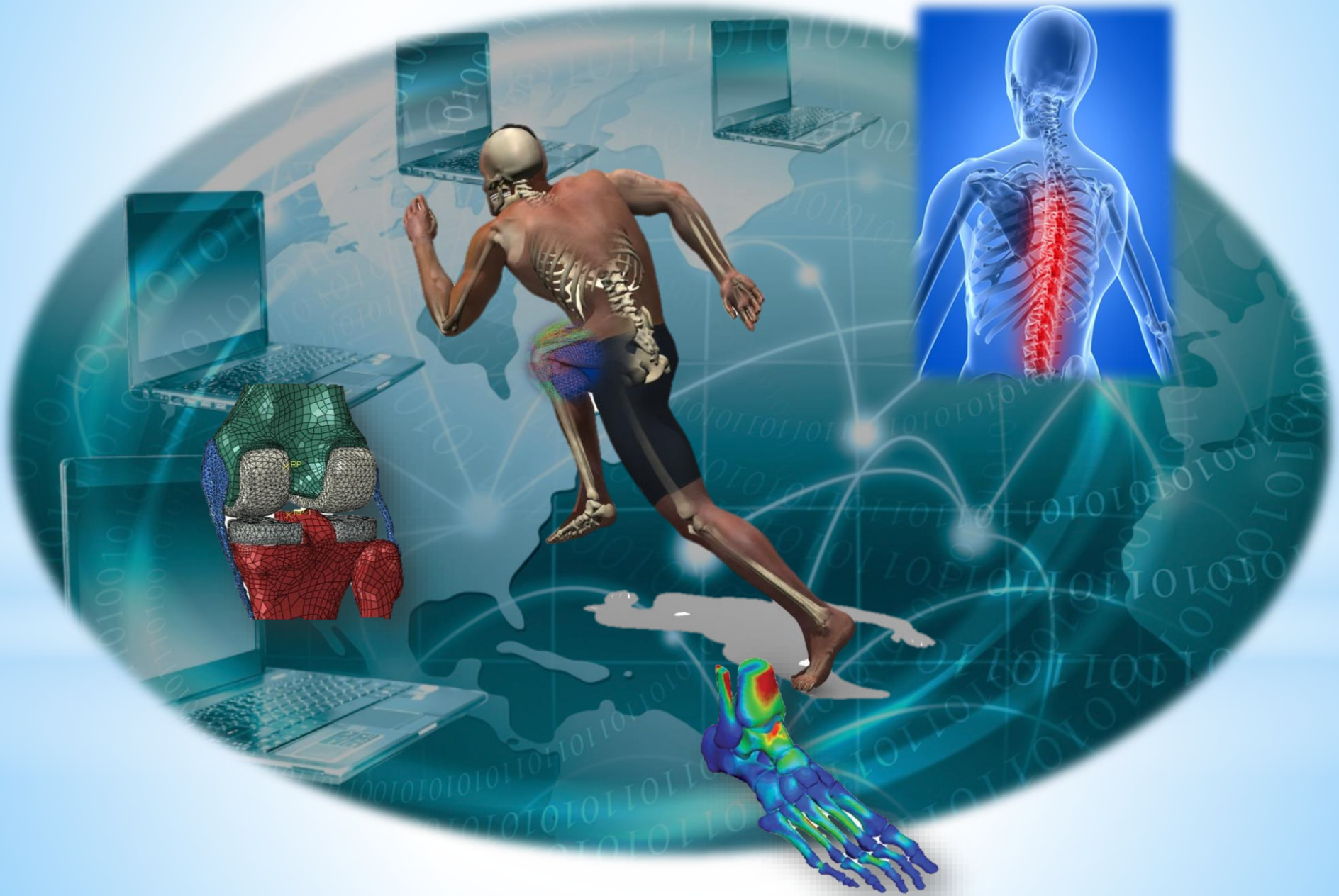
1) Optimize soldier and team performance
2) Develop adaptive and innovative leaders
3) Ensure interoperability
4) Allow for scalable and tailorable joint and combined-arms formations
5) Leverage concepts and technologies to maintain capability overmatch



Humans interact with most products and processes…

Most products and processes are designed on the computer…

Integrated Digital Human Modeling



Integrated Digital Human Model

Integrated Digital Human Model

Trade Off Analysis

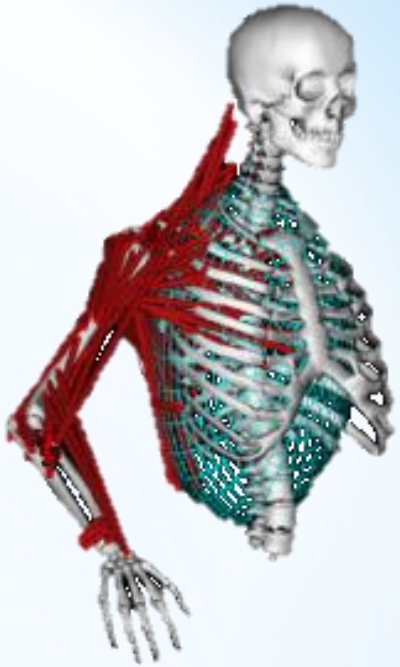
Integrated Digital Human Model

Automated Trade Off Analysis

Integrated Digital Human Model

Coupled Human Systems Integration

Underlying Method



FIND: JOINT ANGLES

TO OPTIMIZE: HUMAN PERFORMANCE MEASURES

SUBJECT TO:

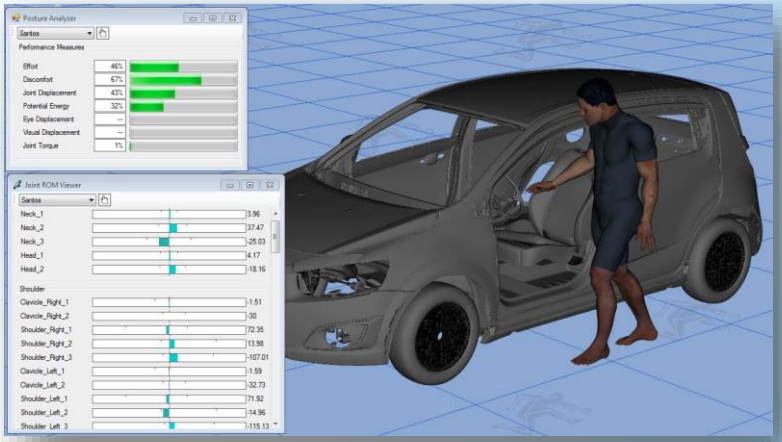
1) DISTANCE BETWEEN END-EFFECTOR AND TARGET POINT — *CONTACT POINTS*

2) ANGLES ARE WITHIN LIMITS — *RANGE OF MOTION*

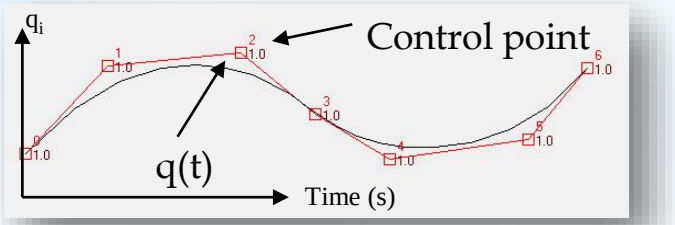
3) COLLISION AVOIDANCE

4) $\boldsymbol{\tau} = \underbrace{\sum_i \mathbf{J}_i^{\mathrm{T}} m_i \mathbf{g}}_{\text{gravity forces}} + \underbrace{\sum_k \mathbf{J}_k^{\mathrm{T}} \mathbf{F}_k}_{\text{external load}}$ — *STATIC EQUILIBRIUM*

5) ZERO-MOMENT POINT — *STABILITY*



Underlying Method



FIND: CONTROL POINTS FOR B-SPLINE CURVES (JOINT ANGLES OVER TIME)

TO OPTIMIZE: HUMAN PERFORMANCE MEASURES

SUBJECT TO:

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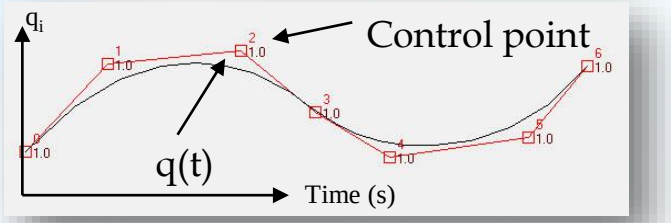
4) ZERO-MOMENT POINT — *STABILITY*

5) $\boldsymbol{\tau} = \underbrace{\mathbf{M}(\mathbf{q})\,\ddot{\mathbf{q}}}_{\text{mass-inertia matrix}} + \underbrace{\mathbf{V}(\mathbf{q},\dot{\mathbf{q}})}_{\text{Coriolis \& Centrifugal}} + \underbrace{\sum_i \mathbf{J}_i^{\mathrm{T}} m_i \mathbf{g}}_{\text{gravity forces}} + \underbrace{\sum_k \mathbf{J}_k^{\mathrm{T}} \mathbf{F}_k}_{\text{external load}}$ — *EQUATIONS OF MOTION*

Underlying Method



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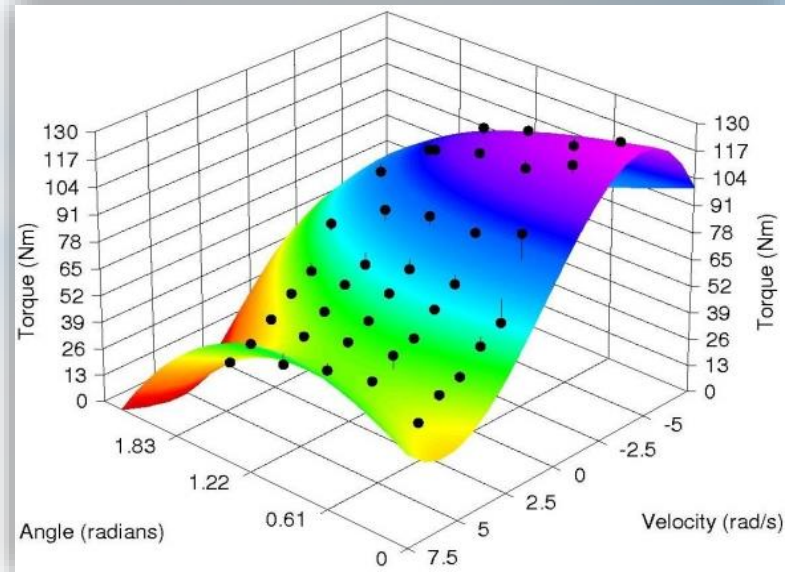
6) STRENGTH LIMITS
7) ADDITIONAL MODELS



Human Performance

- Symmetric/ asymmetric loading
- Quantitative analysis of loading configurations
- Dynamic reaction force visualization
- Center-of-mass movement
- Dynamic torque visualization

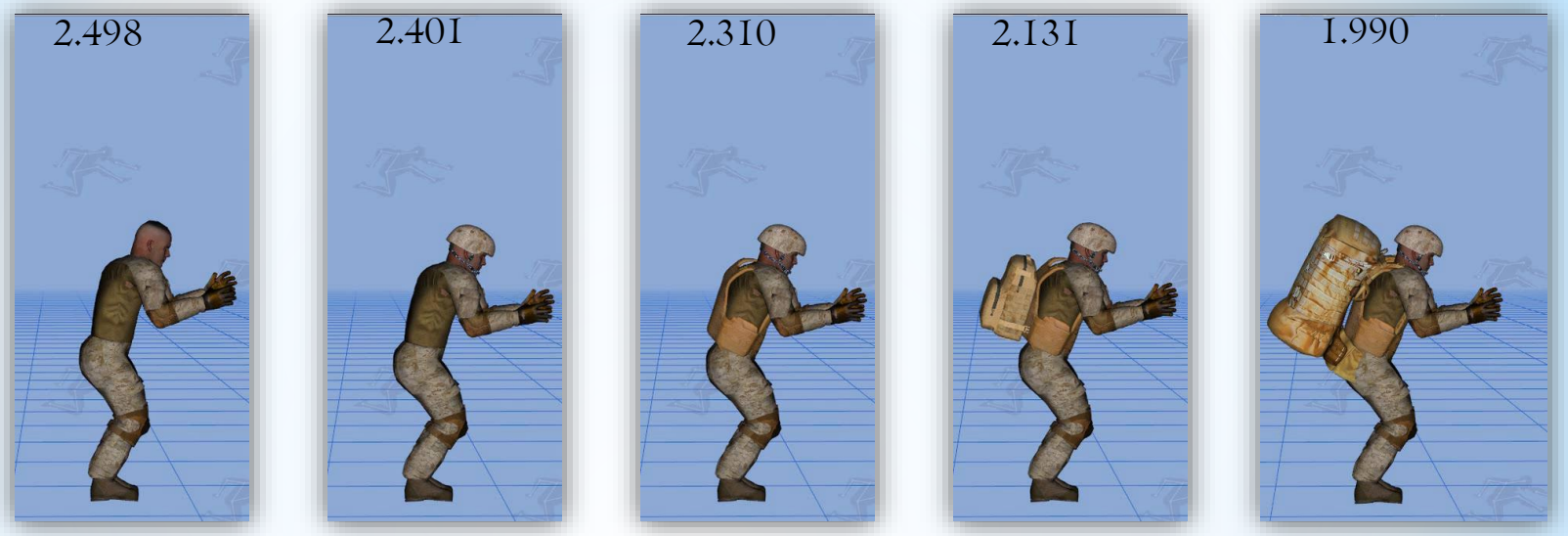
Trade Off Analysis

Trade Off Analysis

See cause and effect with minimal pre-recorded data

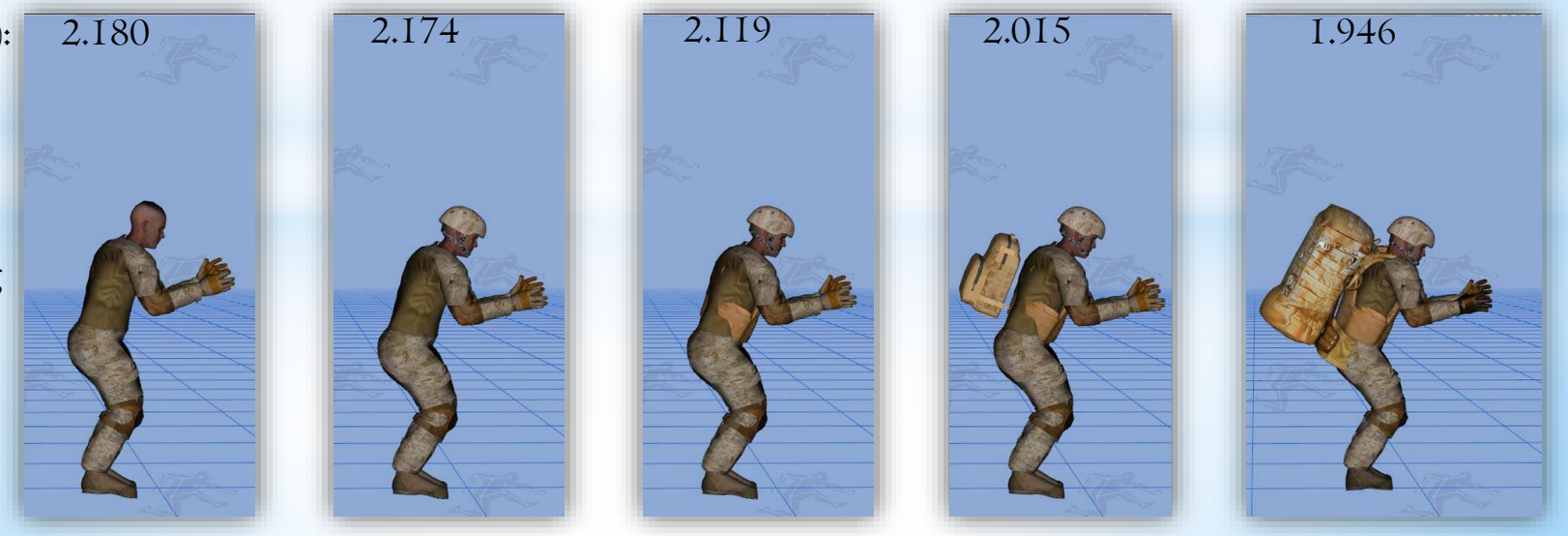
Height (m): 2.498 | 2.401 | 2.310 | 2.131 | 1.990

Santos 79 kg



Height (m): 2.180 | 2.174 | 2.119 | 2.015 | 1.946

Santos 111 kg

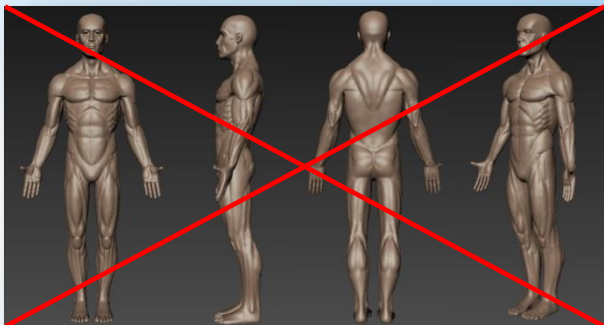


PPE Example

Human system integration (HSI) is insufficiently addressed when designing and analyzing body armor systems and equipment

PPE Example

The design and effectiveness of PPE, and the propensity for survivability depend critically on the task being completed, on the Warfighter anthropometry, and on the position and motion of internal viscera relative to PPE and threats. A static mannequin is insufficient!

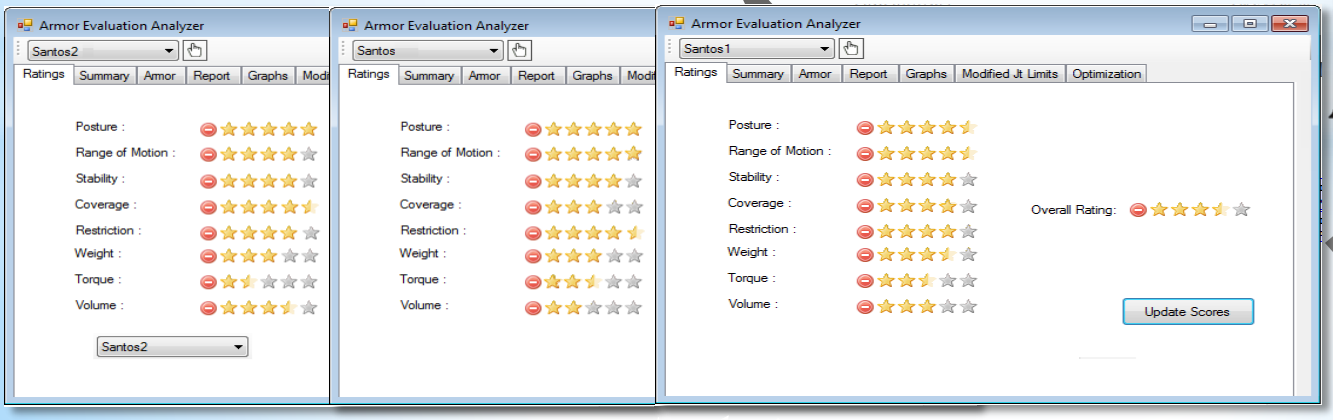


Trade Off Analysis

Simulate Warfighter

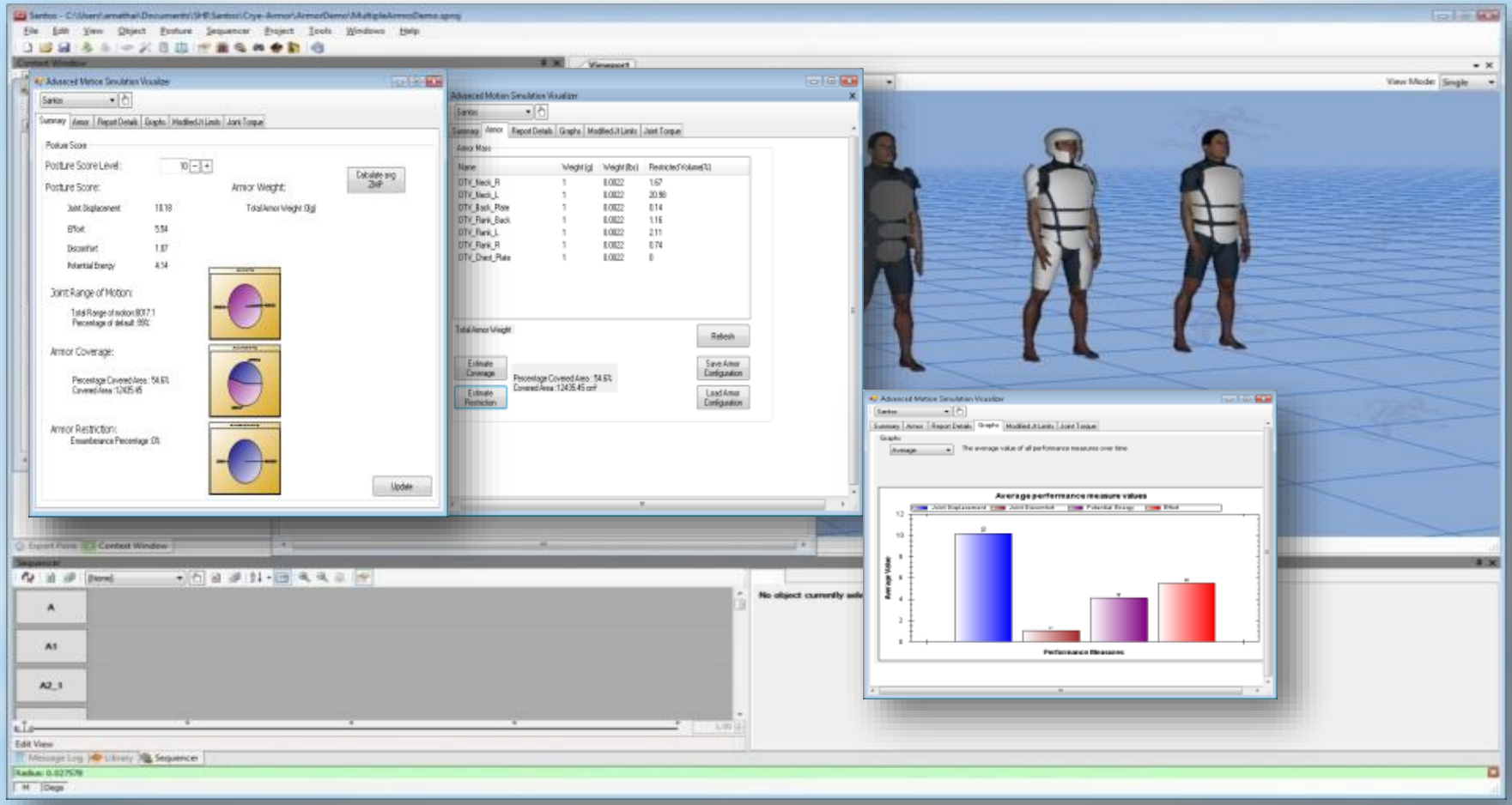
Simulate PPE

Improve PPE

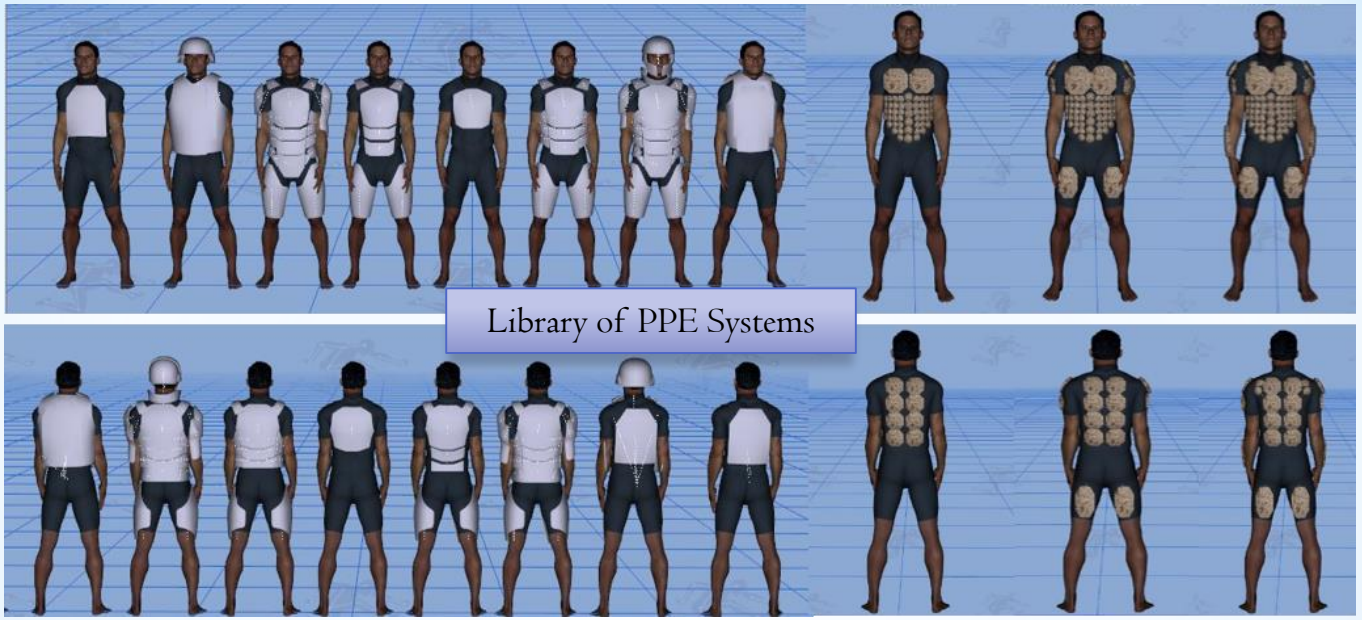


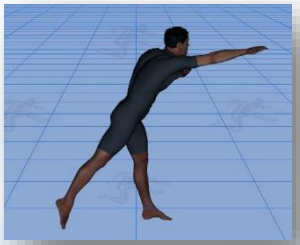
Trade Off Analysis

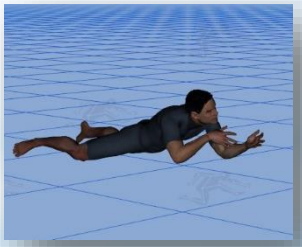
PPE



Automated Trade Off Analysis



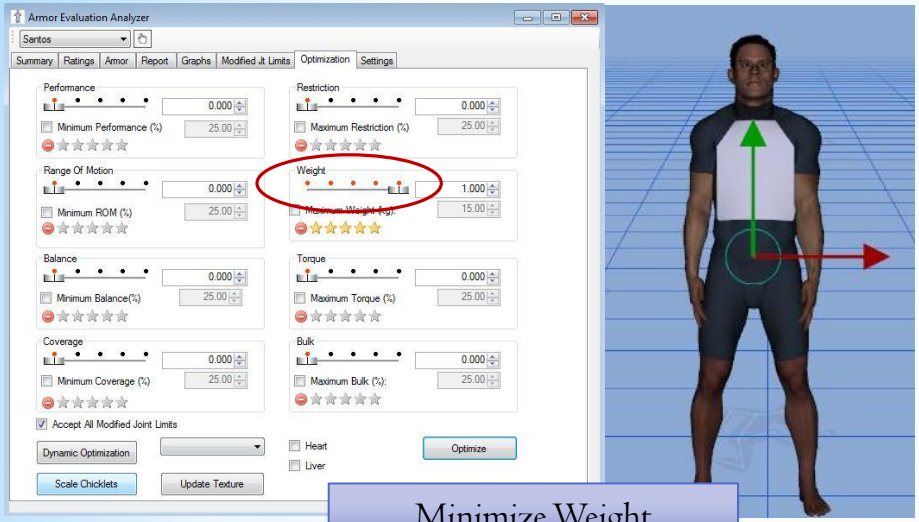




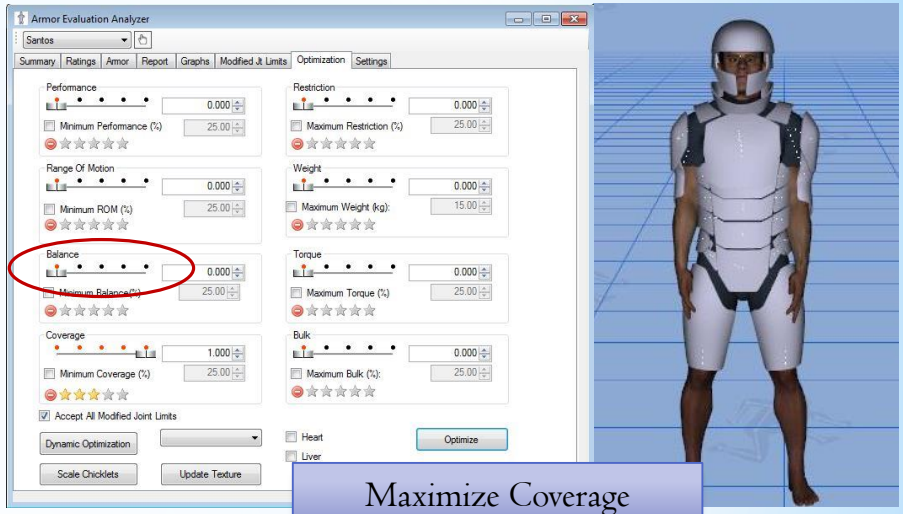
Automatically ***evaluate*** PPE (or other products) based on simulated tasks and specified objectives, and identify optimum systems

Automatically balance mobility, coverage, weight, etc.

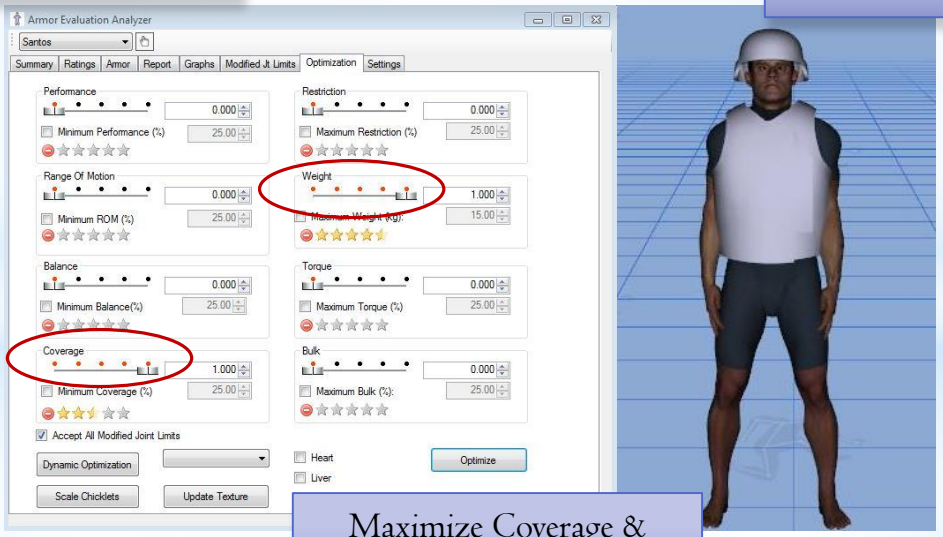
Automated Trade Off Analysis



Minimize Weight



Maximize Coverage



Maximize Coverage &
Minimize Weight

Coupled Human Systems Integration

Hit Detection

Santos

Transparent

Hit Detection | Results | Lambert-Jonas

Blast Device

Marker

Blast

Number of Collisions

500

Display

Armor | Body | Missed | Check All | Uncheck All

Organs:

Heart | Lungs | Liver | Large Intestine

Kidneys | Trachea | Stomach | Small Intestine

Results (% of fragments)

Total Body Hits:

Total Armor Hits:

Total Vital Organs Hit:

Total Avatar Miss:

Hit Detection

Santos

Transparent

Hit Detection | Results | Lambert-Jonas

Blast Device

Marker

Blast

Number of Collisions

400

Display

Armor | Body | Missed | Check All | Uncheck All

Organs:

Heart | Lungs | Liver | Large Intestine

Kidneys | Trachea | Stomach | Small Intestine

Results (% of fragments)

Total Body Hits:

Total Armor Hits:

Total Vital Organs Hit:

Total Avatar Miss:

➢FIND

- Design Variables: z_n, θ_n, e_n

➢TO MAXIMIZE

- $Val = f(\theta_i, z_i) = \sum_{i=0}^{n}(CoverageValue(Hit\ detection\ (z_i, \theta_i))$

➢WHERE

- $Hit\ detection\ (z_i, \theta_i) = u_i, v_i$
- $CoverageValue(u_i, v_i) = Regression(u_i, v_i)$

➢SUCH THAT

- $0 \leq z_i \leq l_i$
- $0 \leq \theta_i \leq 2\pi$
- $(z_i - z_j)^2 + (\theta_i - \theta_j)^2 > r$
- $0 \leq e_i \leq 1$
- $\sum_{i=0}^{n} e_{i} * w_i \leq Max\ Weight$

Find
- Location and existence of armor components

To Optimize
- User defined set of objective functions (i.e. Weight, coverage, survivability)

Subject to
- User defined constraints (e.g. less than 10kg)
- Location bounds

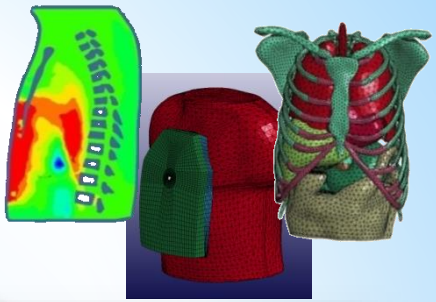
Parameters

$\boldsymbol{z_i}$: The height of the origin location of the ray
$\boldsymbol{\theta_i}$: The lateral location of the origin location of the ray
$\boldsymbol{n}$: The number of component
$\boldsymbol{u_i}$: 2D mapping of body location
$\boldsymbol{v_i}$: 2D mapping of body location
$\boldsymbol{l_i}$: The height of sphere around Santos
r: The radius of an armor component

$\boldsymbol{e_i}$: The existence variable of component i
$\boldsymbol{w_i}$: The weight of component i


Allow More
Material

Coupled Human Systems Integration



➢FIND
- Design Variables: z_n, θ_n, e_n

➢TO MAXIMIZE

➢WHERE
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➢SUCH THAT
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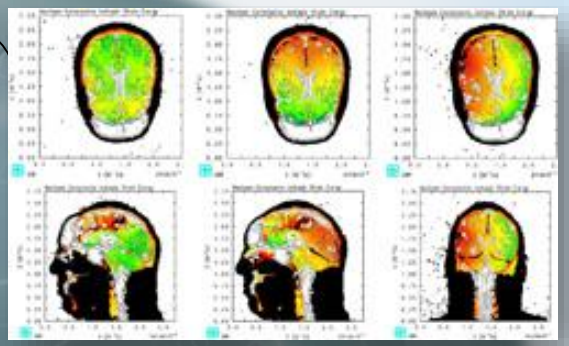
- $\sum_{i=0}^{n} e_{i*w_i} \leq Max\ Weight$



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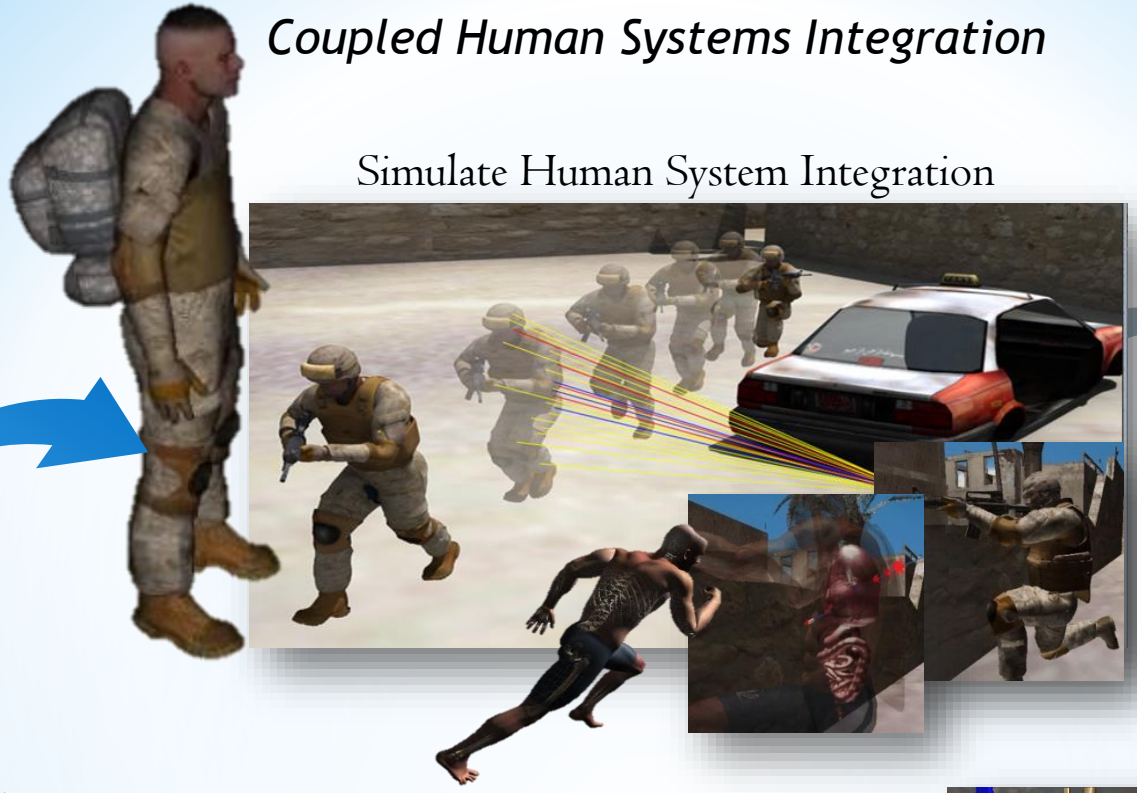
Coupled Human Systems Integration

Simulate Human System Integration



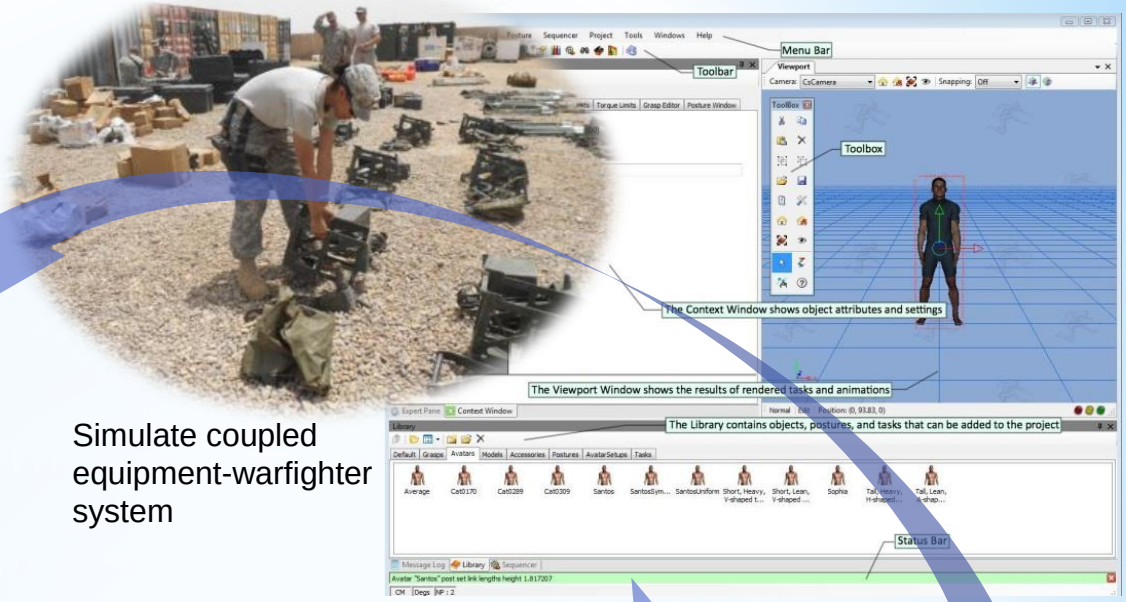
Simulate Vehicle Dynamics

Simulate the Blast

High Fidelity Injury Models

Use human reactions and propensity for injury to automatically impose optimal design changes that reduce injury

Coupled Human Systems Integration



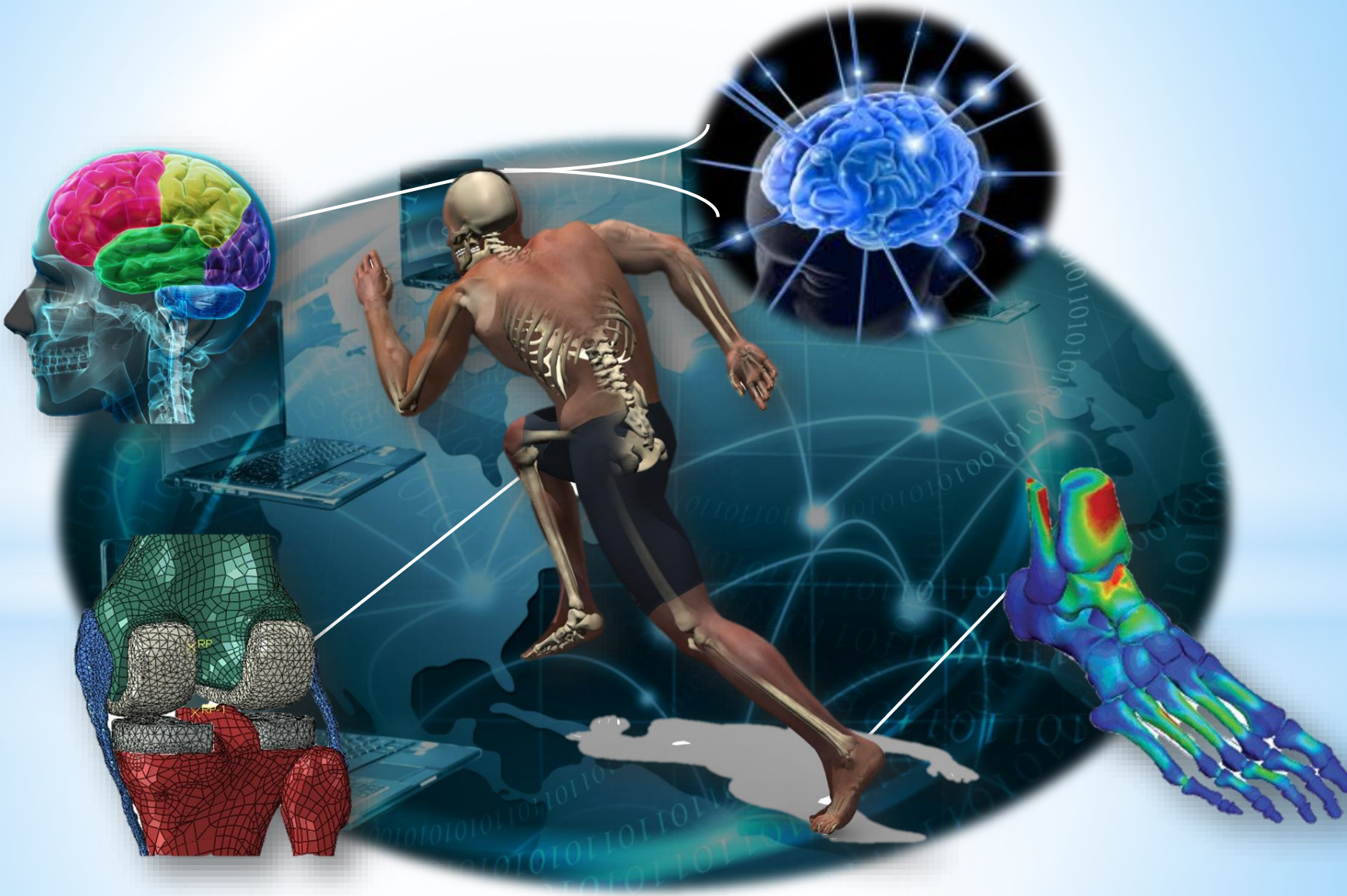
Inform the squad

Simulate coupled equipment-warfighter system

<u>Mission Optimization</u>
Automatically Evaluate & Optimize Squad Performance (load balancing)

Distribute equipment to squad and to individuals

Simulate physiological performance


RP
RP-1

Predictive Human Models and the Third Offset

Optimization-Based Coupled Human Systems Integration

SANTOSHUMAN®

Motivation

Squad leaders lack adequate information, and there are no means for analytic support for situational assessment or dissemination of recently acquired knowledge. There is no method in place for capturing unique experiential field-knowledge, and the training process for squad leaders has not been formalized.

There needs be a ***better organization and deployment of squad leader training tools***, and that new tools be developed to prepare leaders for the more complex in-theater experience.

There is a ***lack of a systems*** or protocols ***to retain unique experiential field knowledge*** that would be valuable to other squad leaders.

There is a need for investment in S&T research to ***enhance decision-making with tools such as smartphone applications*** for situational assessment and course-of-action evaluation, as well as training simulators that can be adapted on the fly, to suite various in-theater situations.

Committee on Improving the Decision Making Abilities of Small Unit Leaders, 2012

Lighten the Load

Mission
Equipment

An expert system that learns…

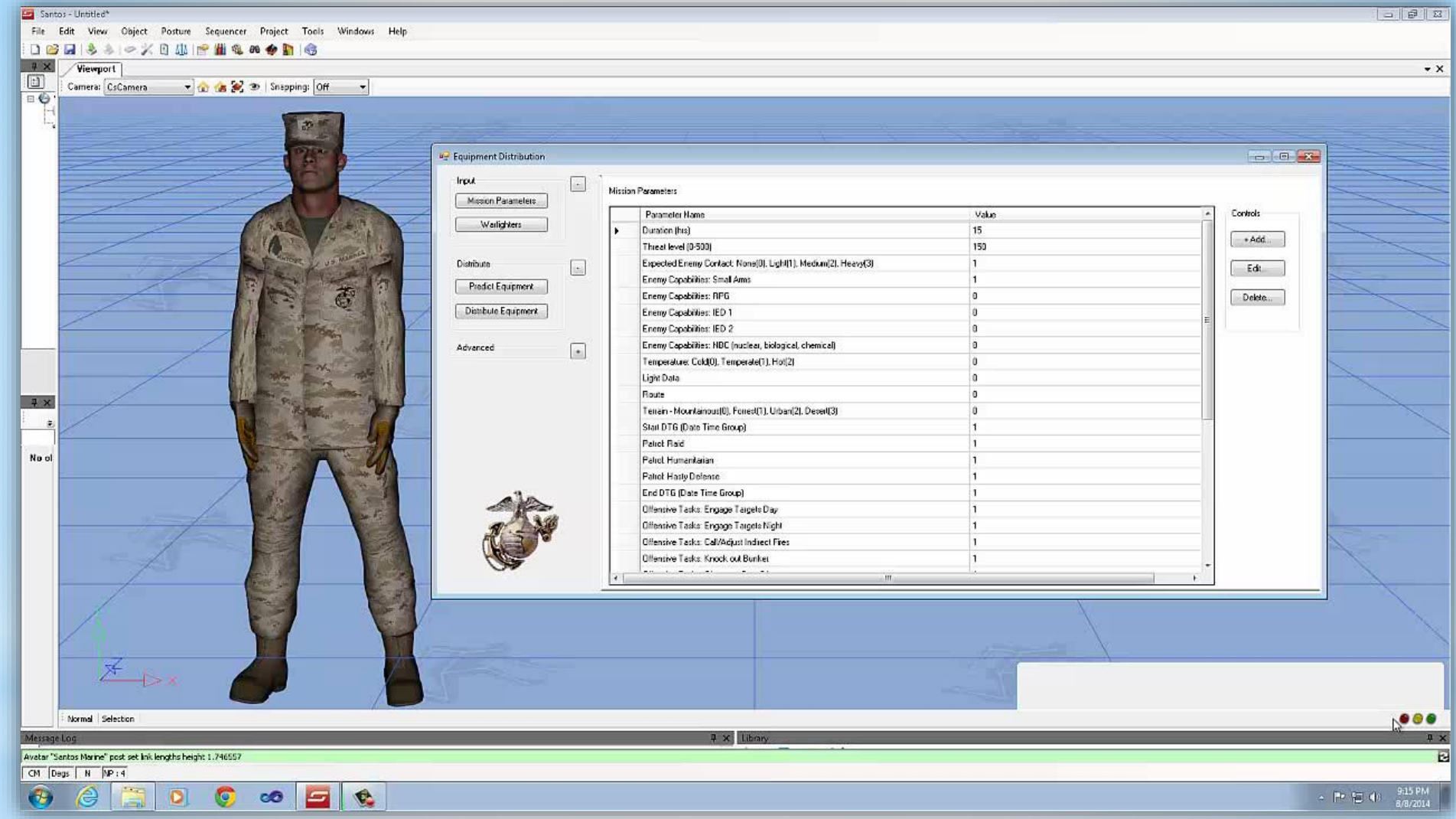
Input:
Squad leader adds new information as needed:
- Which Warfighters are involved in a mission
- Mission parameters
- Warfighter characteristics
- Equipment loads carried by a Warfighter
- Dependencies

Subject to:
- Mission-equipment dependencies

To Optimize:
Weight of equipment taken on a mission

Lighten the Load

Equipment Distribution



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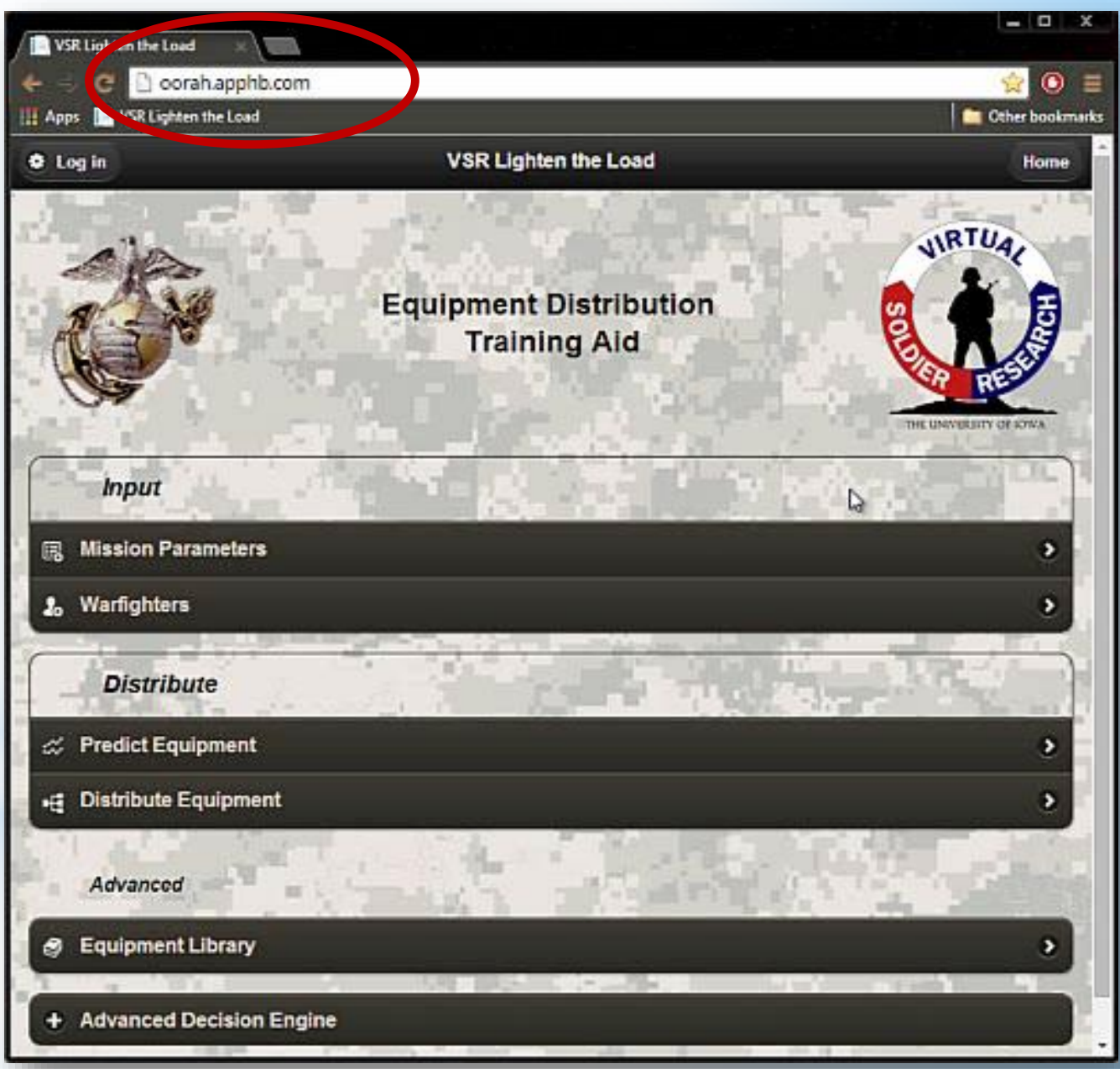
Lighten the Load

Equipment Distribution

Tools that provide a secure server-based method for aggregating squad knowledge and training new leaders



Lighten the Load

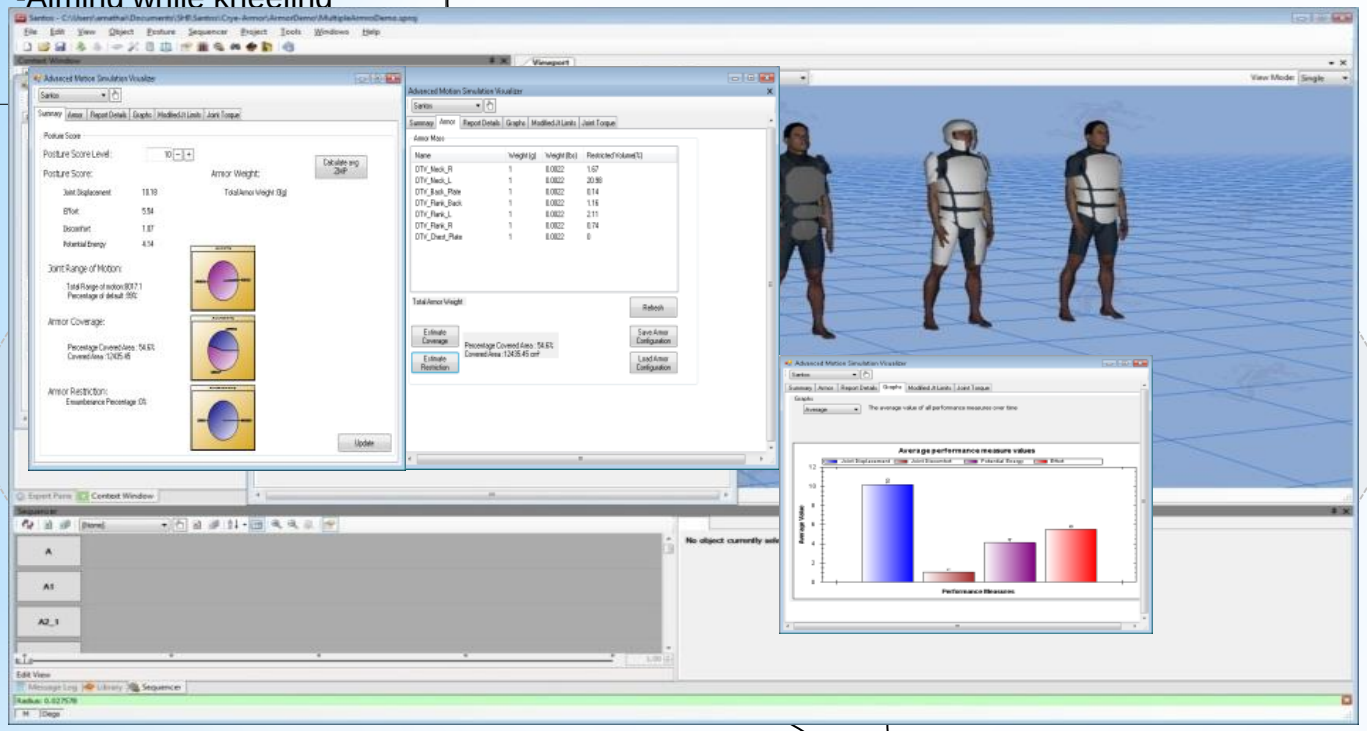
Integration with Human Performance

…and that link with full human performance evaluation

Biomechanical Effects of PPE

Analysis

Armor-evaluation Tasks
-Arm raises
-Sitting
-Aiming while standing
-Aiming while kneeling



Evaluation Metrics
-Performance
-Mobility
-Balance
-Coverage
-Restrictive Volume
-Weight
-Torque
-Bulk

Evaluate the ability to perform tasks, based on a suite of metrics