Development of a Hierarchical Estimation Method for Anthropometric Variables

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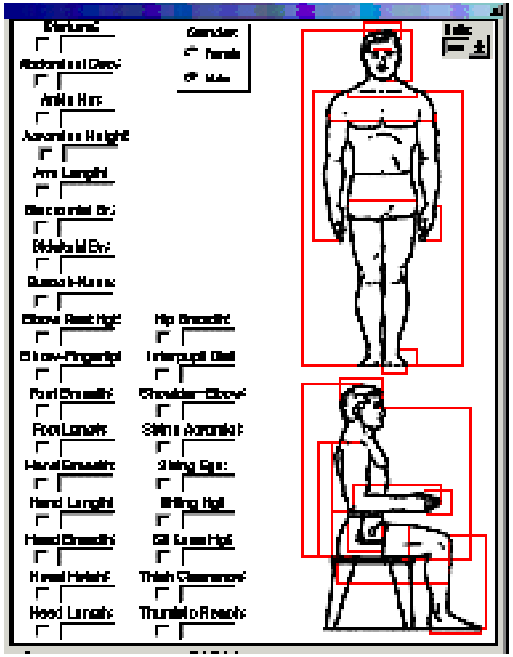
Agenda

- Background: ‘Flat’ Estimation Method
- Objectives of the Study
- Development of the Hierarchical Estimation Method
- Comparison of Flat and Hierarchical Models
- Discussion

Use of Regression Models in Anthropometry

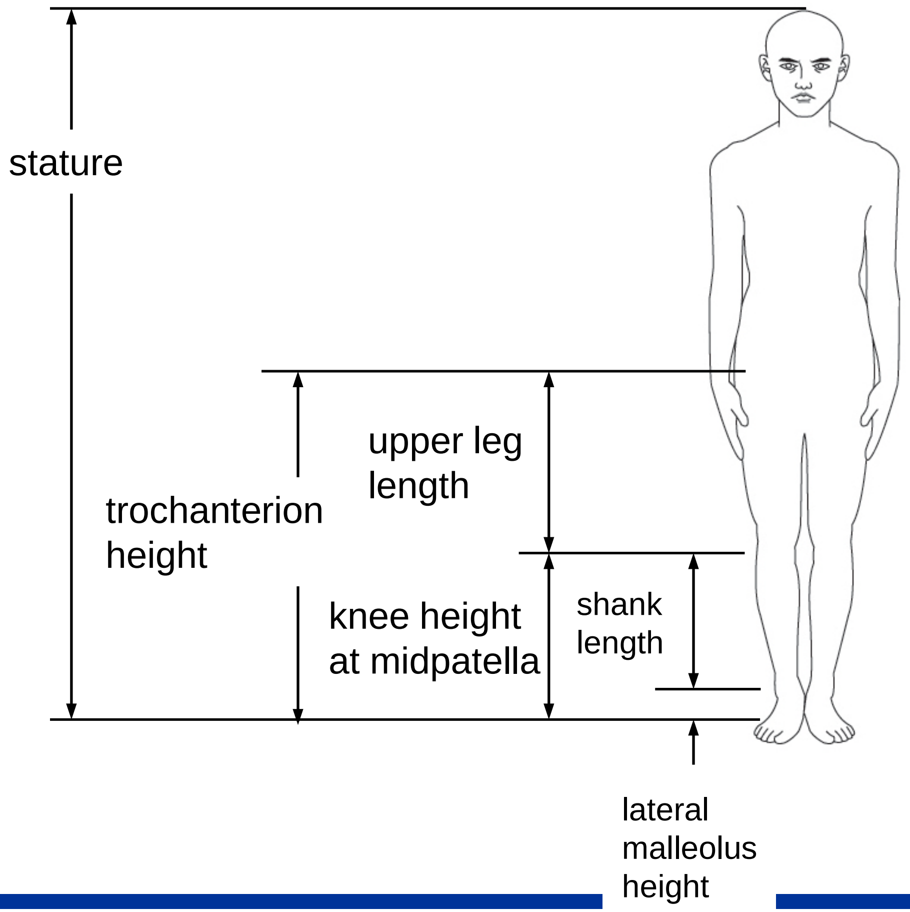
- Estimation of measurements of body dimensions unavailable
- Applications: Ergonomic design; sizing digital human models



Flat Regression Models

- Most regression models provided in anthropometry include only stature and/or weight as regressor(s) to estimate body dimensions.

trochanterion height = f_1(stature)
upper leg length = f_2(stature)
knee height at midpatella = f_3(stature)
shank length= f_4(stature)
lateral malleolus height = f_5(stature)



Limitation of Flat Estimation Method

- Unsatisfactory estimation for an anthropometric variable having a low value of *r* with S and/or W.

(e.g.) biacromial breadth = *f*(stature)

r	R^2	SE (cm)	SD (cm)
0.48	0.24	15.69	17.96

(1988 US Army anthropometric survey)

⇒ Resulting in low utility of regression models in estimation.

Hierarchical Estimation

- Employ different regressors in regression models in a hierarchical manner by considering the anatomical and statistical relationships between anthropometric variables.

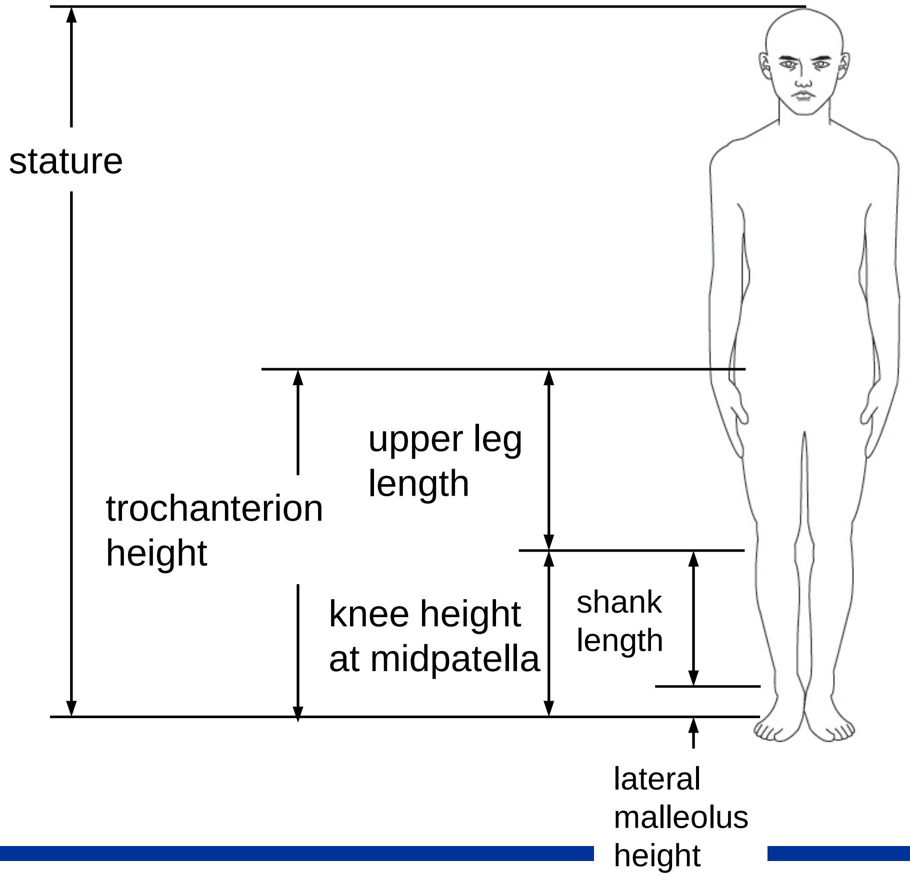
trochanterion height = g_1(stature)

upper leg length = g_2(trochanterion height)

knee height = g_3(trochanterion height)

shank length = g_4(knee height)

lateral malleolus height = g_5(knee height)



Objectives of the Study

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- Develop a method to establish hierarchical regression models for anthropometric variables in a systematic manner by considering the geometric relationships of the AVs.

- Examine the effectiveness of the hierarchical estimation method in comparison with the flat estimation method
  - ✓ 1988 US Army anthropometric survey data
  - ✓ 59 AVs selected for application to design of an occupant packaging layout

Procedure for Hierarchical Estimation Structures

- 4-step procedure to establish hierarchical estimation structures of anthropometric variables for regression.

S1: Grouping anthropometric variables

(1) length/height variables
(2) width/depth/circumference variables

↓

S2: Analyzing geometric relationships

(1) combinatory relationships
(2) inclusive relationships

↓

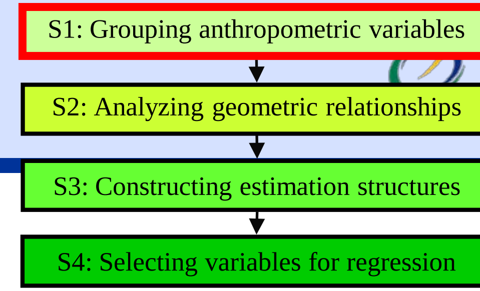
S3: Constructing estimation structures

(1) length/height estimation structure
(2) width/depth/circumference estimation structure

↓

S4: Selecting variables for regression

S1: Grouping AVs



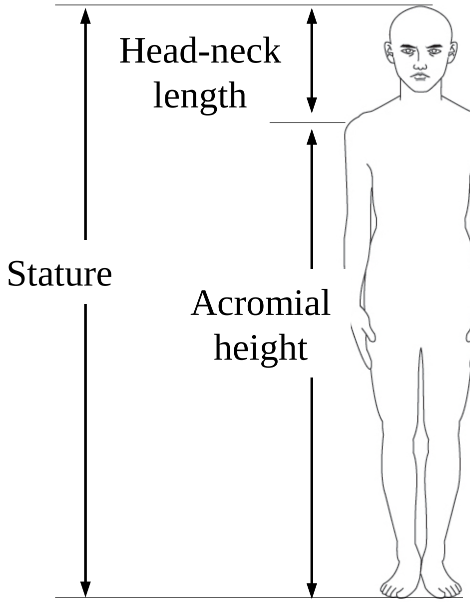
- Group AVs under consideration into two dimensional categories:
  - (1) length/height variables
  - (2) with/depth/circumference variables

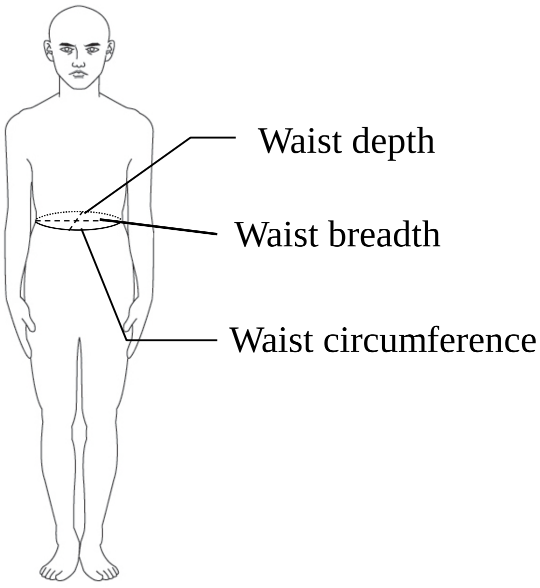
⇐ Length/height variables are more closely related to each other than width/depth/circumference variables and vice versa (Rosenblad-Wallin, 1987).

⇐ Confirmed in the present study with the US Army data.

S2: Analyzing the Geometric Relationships of AVs

Combinatory	Inclusive
A set of AVs in which one variable can be represented by a linear combination of the other variables	





S2: Analyzing the Geometric Relationships of AVs

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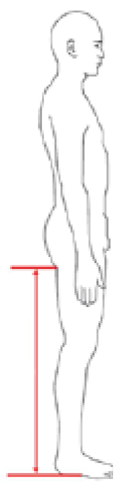
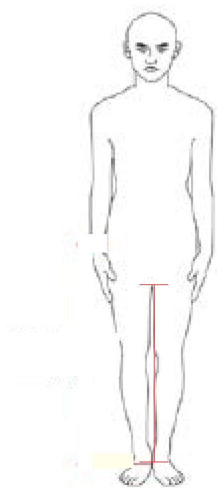
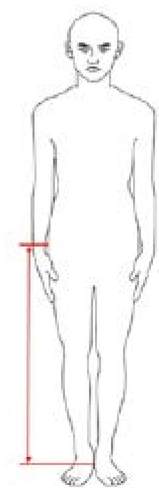
Combinatory	Inclusive
A set of AVs in which one variable can be represented by a linear combination of the other variables	A pair of AVs in which both the variables measure the same body segment(s) but one variable measure a part of the other variable by using different landmarks and/or in different postures



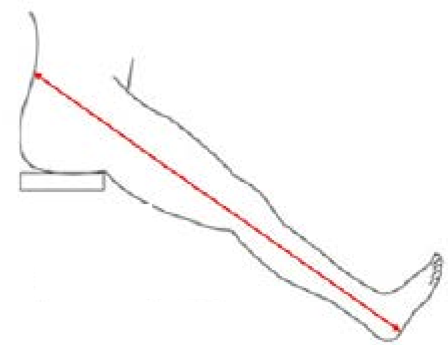
Gluteal furrow height



Crotch height



Trochanterion height



Functional leg length

Analysis of AVs: Length/Height (example)

Geometric Relationship	No	Group
Combinatory	1	stature, head-neck length, acromial height
	2	acromial height, chest-back length, waist height at omphalion
	3	waist height at omphalion, abdomen-hip length, trochanterion height
	4	trochanterion height, upper leg length, knee height at midpatella
	5	knee height at midpatella, shank length, lateral malleolus height
Inclusive	1	acromial height, cervical height
	2	acromial height, axilla height
	3	trochanterion height, functional leg length
	4	trochanterion height, crotch height
	5	trochanterion height, gluteal furrow height

S3: Constructing Hierarchical Estimation Structures

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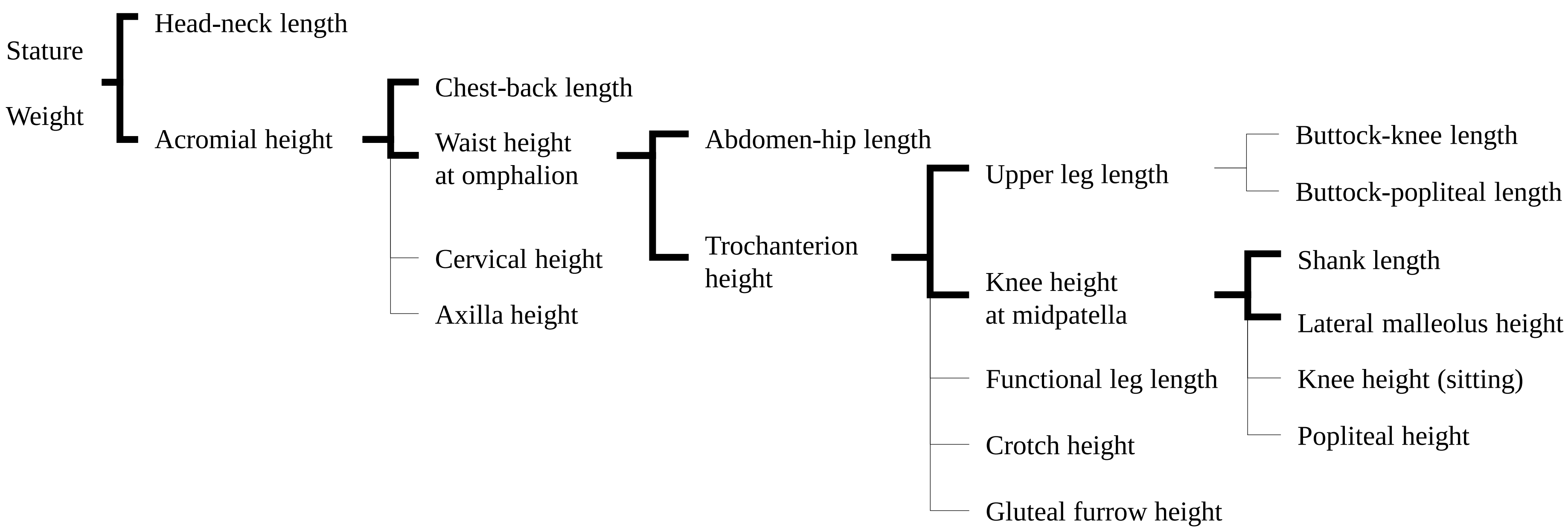
- Hierarchical estimation structures for length/height and with/depth/circumference AVs.
- First framed with AVs in combinatory relationships and then completed by adding AVs in inclusive relationships.



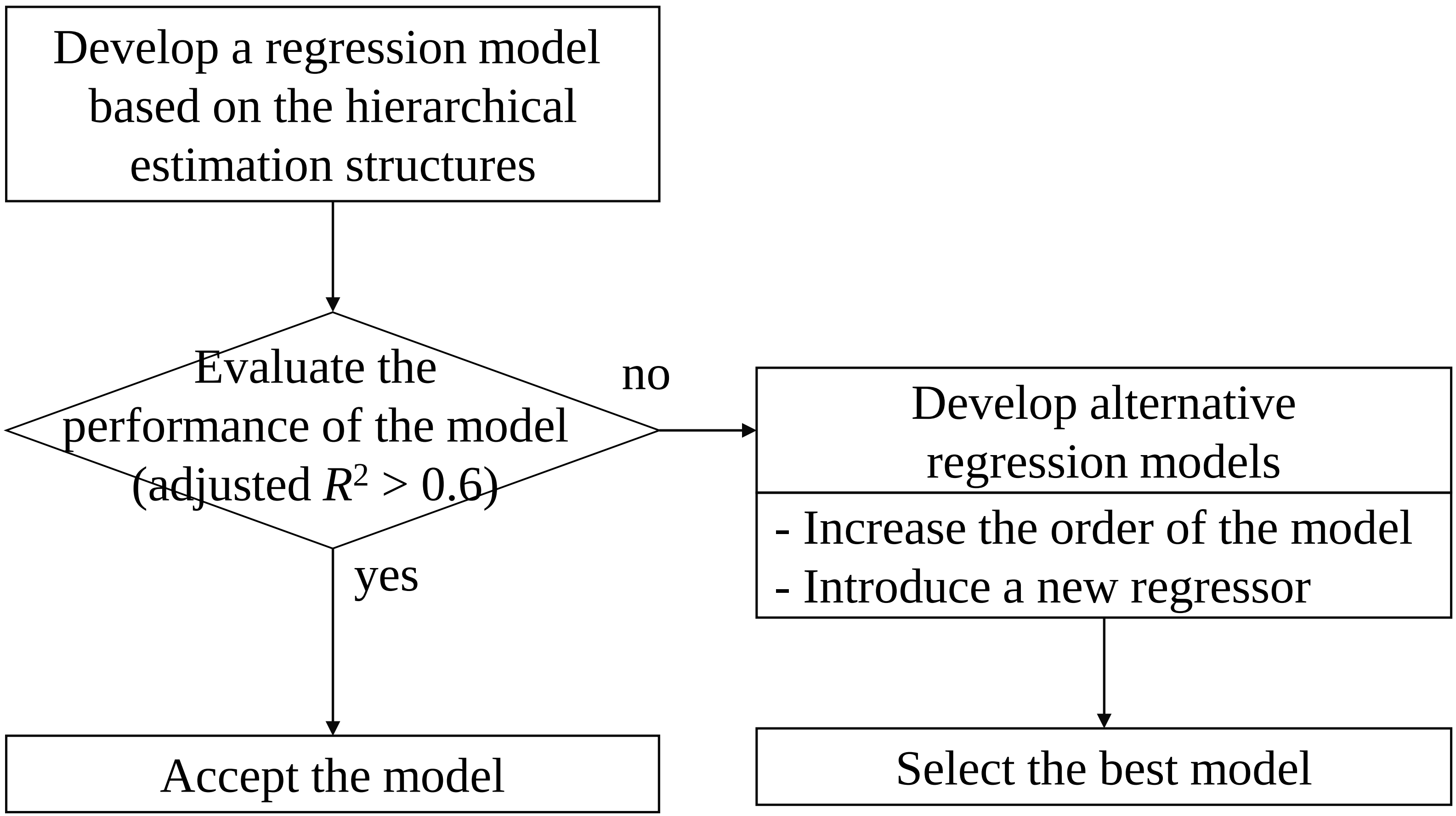
S4: Selecting AVs for Regression

- For each group of AVs in combinatory relationship, one variable is determined if the other variables are known.

- When a regressor is determined, one with a higher correlation is selected for regression and the other for estimation by the corresponding combinatory relationship.

Stature
- Head-neck length — $r = 0.39$ — HN length = Stature – AH
- Acromial height — $r = 0.96$ — AH = f(stature)

Regression Model Development Process



Regression Model Improvement (example)

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- Models for buttock-knee length

Regressors included	adjusted R^2	Remark	Selection
Upper leg length	0.55	Based on the corresponding hierarchical estimation structure	
Upper leg length, (upper leg length)^2	0.55	Increased the order of the regressor	
Functional leg length	0.83	Introduced a new regressor	O

Hierarchical Regression Models: Trunk (example)

Dimension Type	Body Dimensions	Gender	Regression Model	SE	Adj. R^2
Length/ height	Acromial height	M	-101.311 + 0.863×Stature + 0.036×Weight	16.0	0.933
		F	-86.125 + 0.859×Stature + 0.031×Weight	14.3	0.939
	Waist height at omphalion	M	-25.430 + 0.752×Acromial height	20.5	0.838
		F	-54.981 + 0.778×Acromial height	18.9	0.851
	Axilla height	M	-11.573 + 0.924×Acromial height	9.1	0.975
		F	-3.649 + 0.928×Acromial height	8.1	0.978
Width/depth/ circumference	Bideltoid breadth	M	395.859 - 0.039×Stature + 0.209×Weight	13.8	0.716
		F	331.865 - 0.026×Stature + 0.230×Weight	13.2	0.662
	Biacromial breadth	M	-43.067 + 0.639×Bideltoid breadth + 0.108×Stature - 0.081×Weight	12.0	0.554
		F	-63.540 + 0.682×Bideltoid breadth + 0.121×Stature - 0.107×Weight	11.5	0.562

Flat vs. Hierarchical Models

- Of 54 hierarchical models, 45 models have regressors other than stature and weight.

	Performance Difference			
	Measure	Average	Min.	Max.
Better performance: 39 hierarchal models	Adjusted R^2	0.209	0.002	0.627
	SE (mm)	4.4	0.004	16.3
Lower performance: 6 hierarchal models	Adjusted R^2	0.058	0.006	0.103
	SE (mm)	1.7	0.400	3.4

Discussion

- Developed a method which estimates AVs in a hierarchical manner based on the geometric relationships between the AVs.

- Demonstrated that hierarchical regression models are preferred overall to flat regression models for better adequacy of fit (adj. R^2) and estimation accuracy (SE).
  - ✓ Of 45 hierarchical models, 39 models showed a 55% increase in adjusted R^2 and a 31% decrease in SE on average when compared to the corresponding flat models.

Q & A

Thank you for your attention…