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Sensor Self-Report Alignment (SSRA): Reducing Sun Exposure Assessment Error

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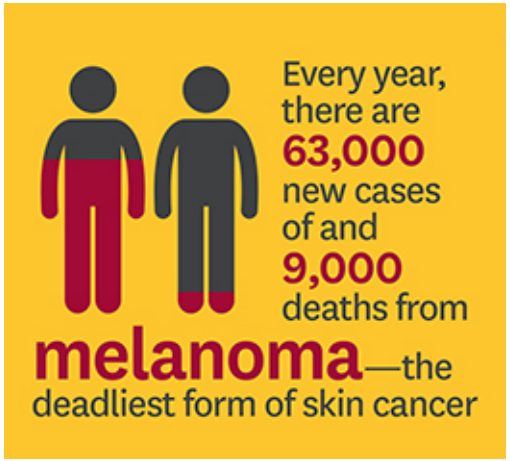
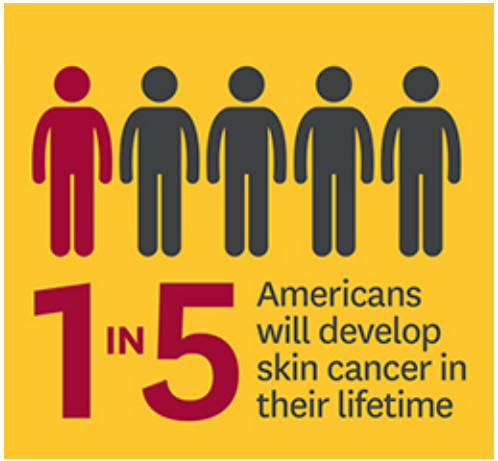
The need to study sun exposure



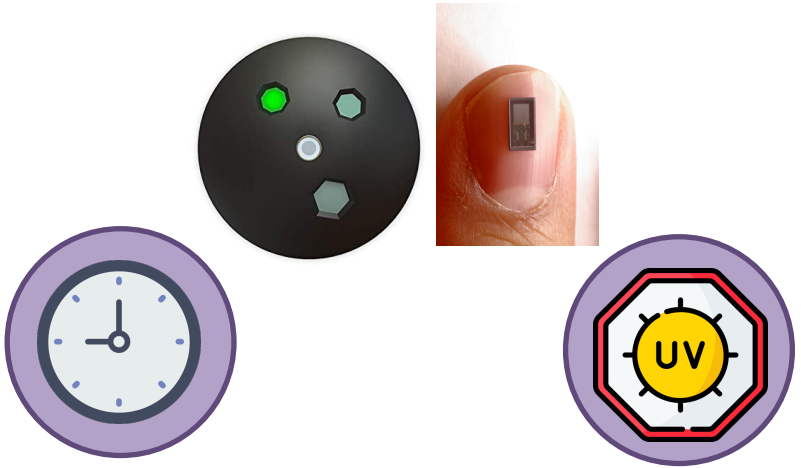


Thus, there is a need for more research designed to understand and intervene upon sun exposure and physical activity.

Measuring sun exposure

Self-reports

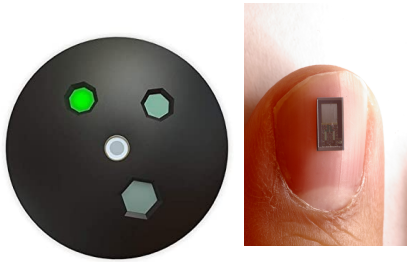
Automated sensors



Is one better than the other?

Both measures offer us unique information which when combined will improve our understanding of sun exposure.

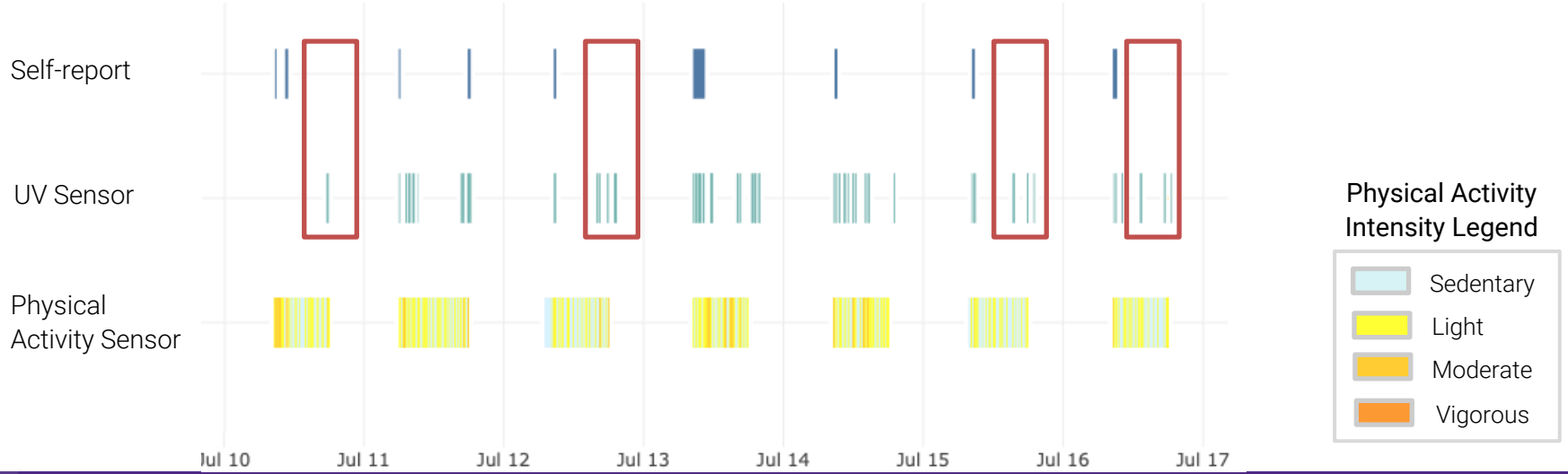
- Recall bias
- Low adherence
+ Contextual information



+ High adherence
+ Precise measurements
- No contextual information

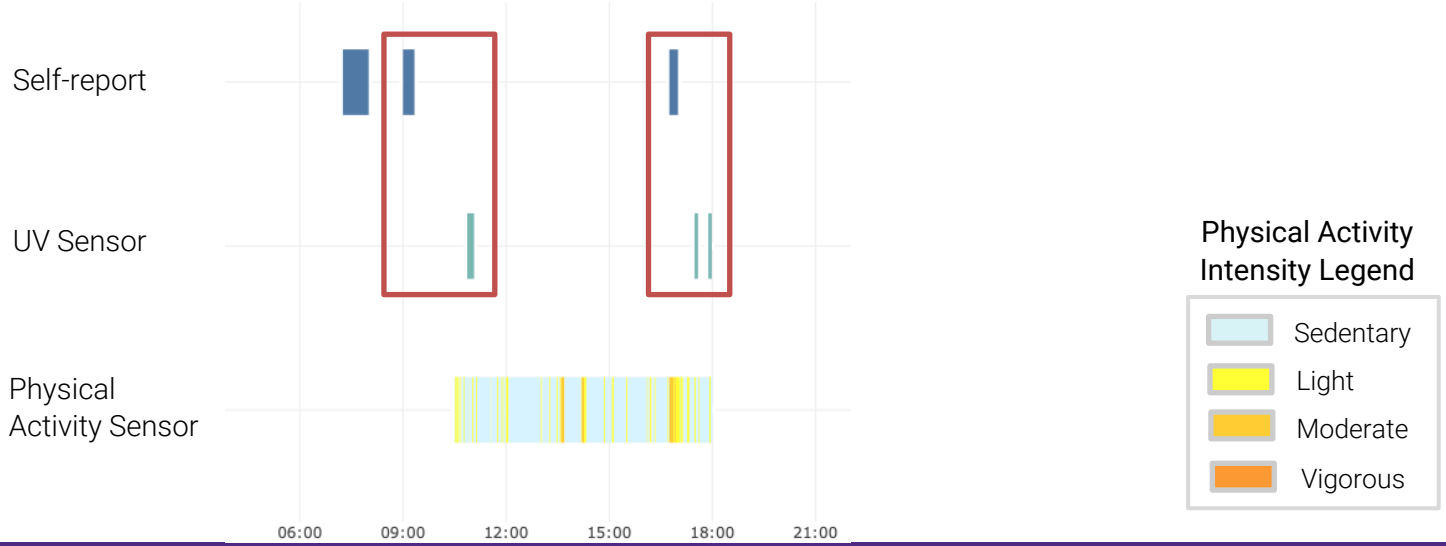
Real World Data

- Person prefectly recalls all sun exposure events from their day in the self report.
- But this seldom happens.

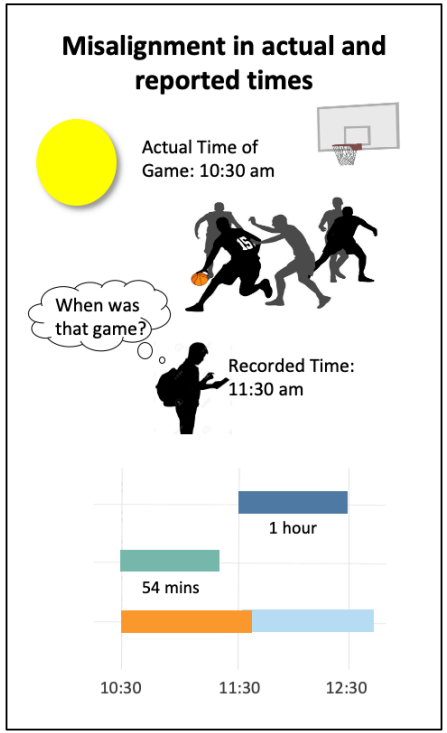


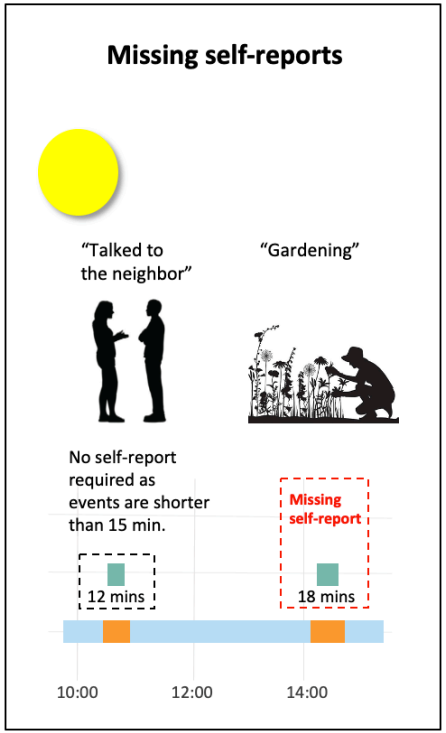
Real World Scenario

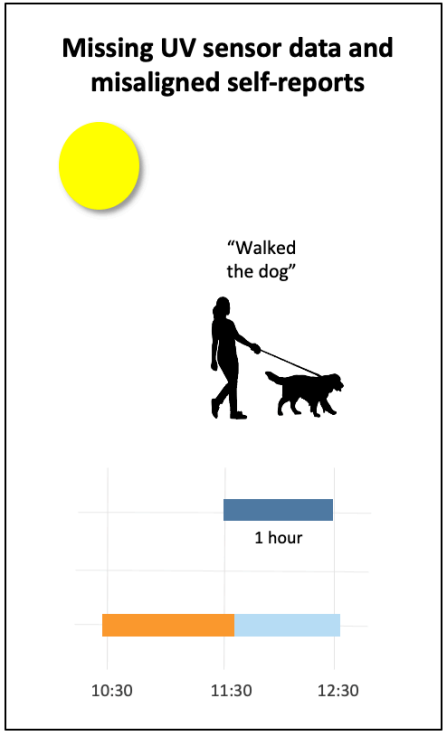
- Person prefectly recalls all sun exposure events from their day in the self report.
- But this seldom happens.



Challenges with combining measures







Self-report

UV Sensor

Physical Activity Sensor

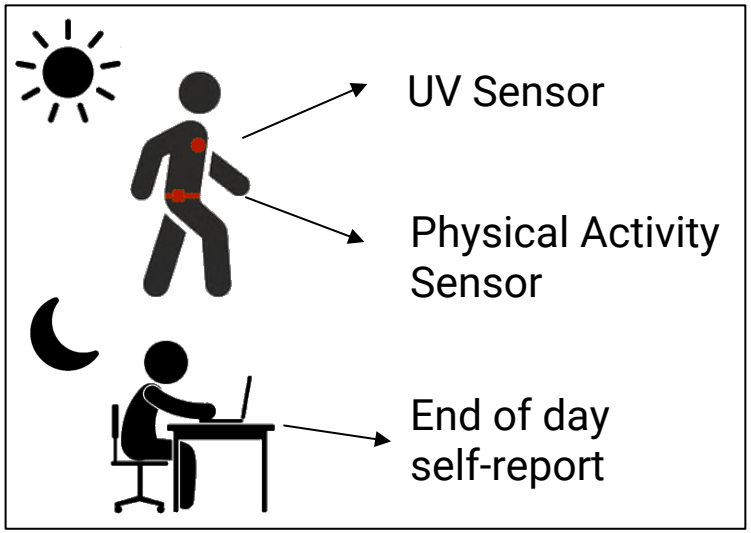
Aim

- Develop a framework to **align self-report**, **chest-worn UV** sensor and **hip-worn physical activity** sensor to adjust for misalignment between them.

- Analyze:
  - Number of false positive and false negative minutes between sensor and self-report measures
  - Protection adjusted UV dose per body site
  - Outdoor physical activity minutes

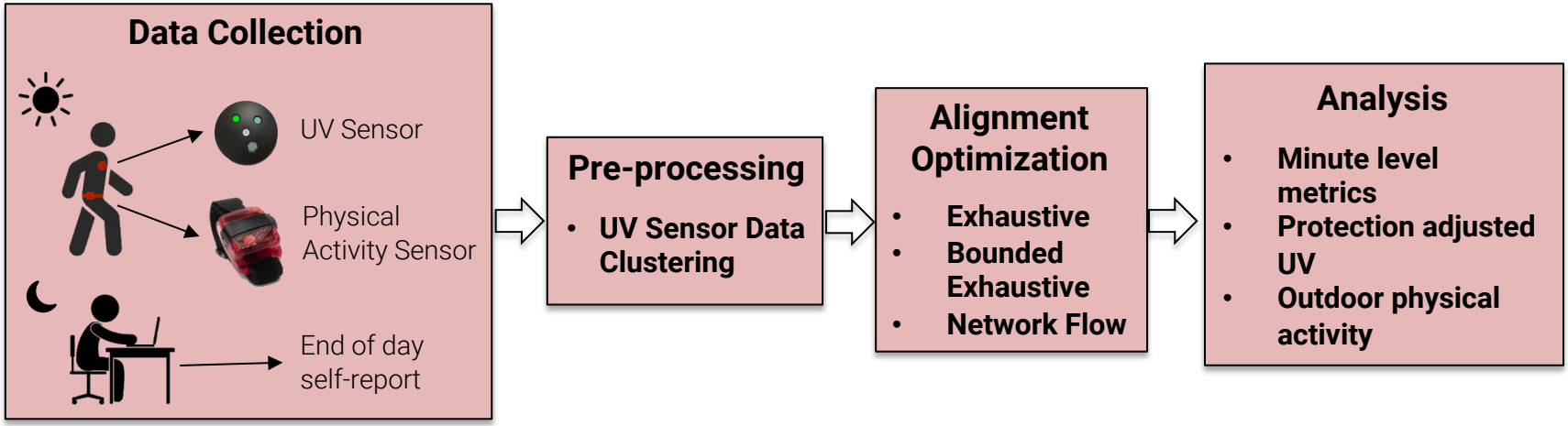
Study Overview

- 40 particpants
  - 20 melanoma surviors
  - 20 young adult first degree relatives of melanoma survivors



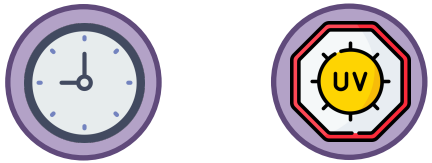
X 7 days

Sensor Self-Report Alignment (SSRA)

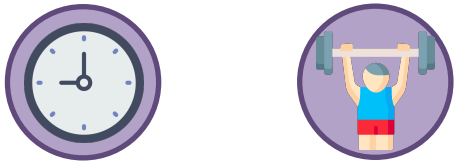


Data Collection

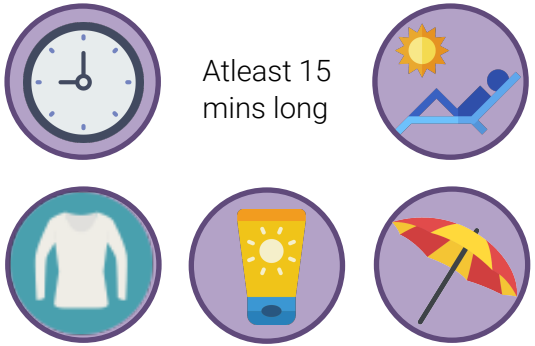
UV Sensor – Shade[1]



Physical Activity Sensor – Actigraph[2]



Self-report – MUSE[3]



1: https://www.wearshade.com

2: https://www.actigraphcorp.com

3: Stump, Tammy K., et al. "Daily Minutes of Unprotected Sun Exposure (MUSE) Inventory: Measure description and comparisons to UVR sensor and sun protection survey data." Preventive medicine reports 11 (2018): 305-311.

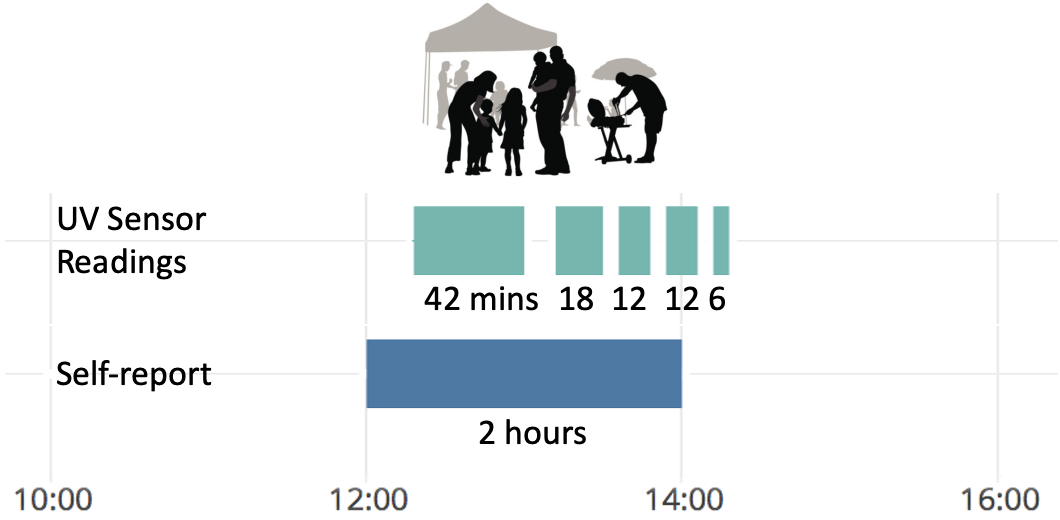
Preprocessing

- 40 participants had 254 days of data
  - Participant noncompliance
  - Minor technical issues (dead battery)
  - Lack of sensor wear

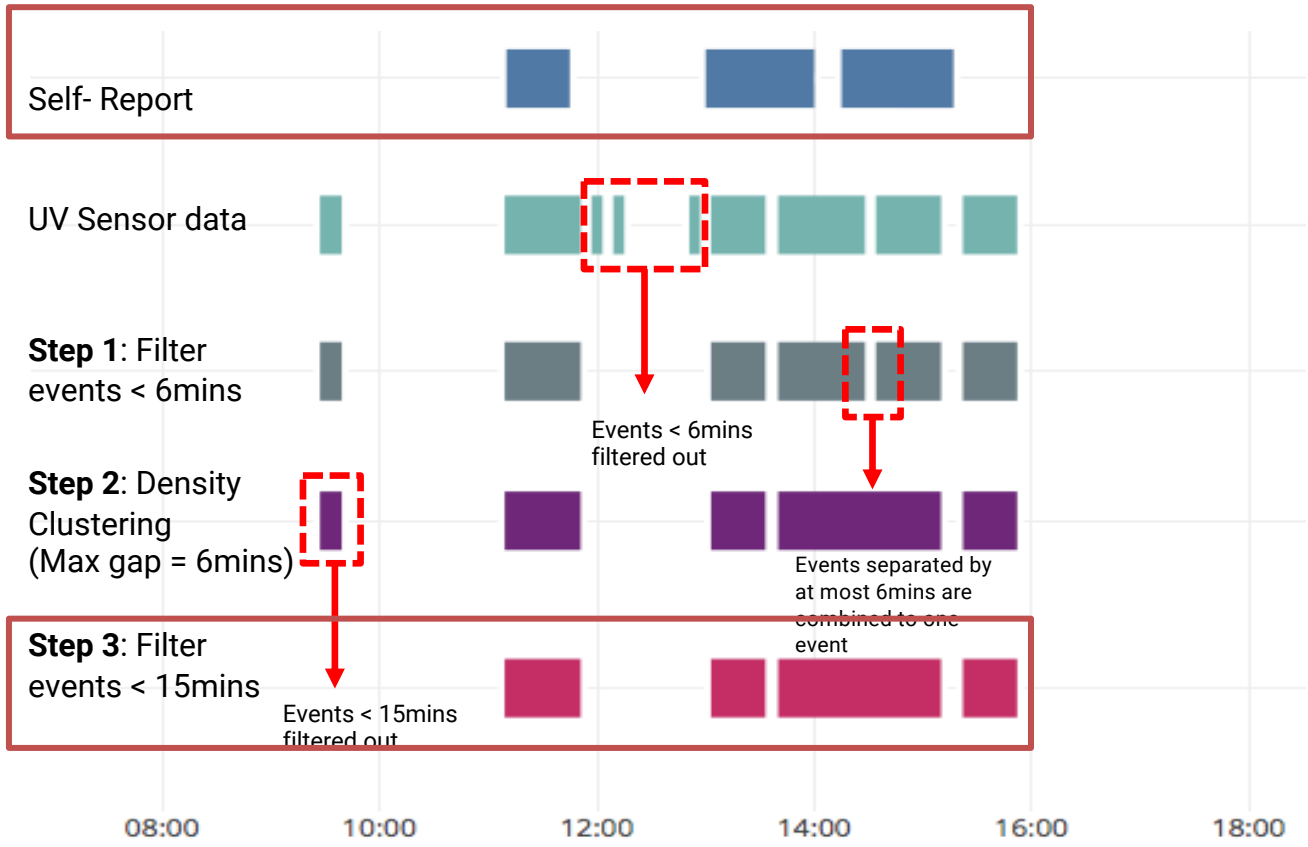
	Total (in hrs)	Avg per particpant (in hrs)	Avg per day (in hrs)
Self-report	373.2	9.33	2.13
UV Sensor	586.93	14.67	2.35
Physical Activity Sensor	2467.35	61.88	9.71

UV Sensor Data Clustering

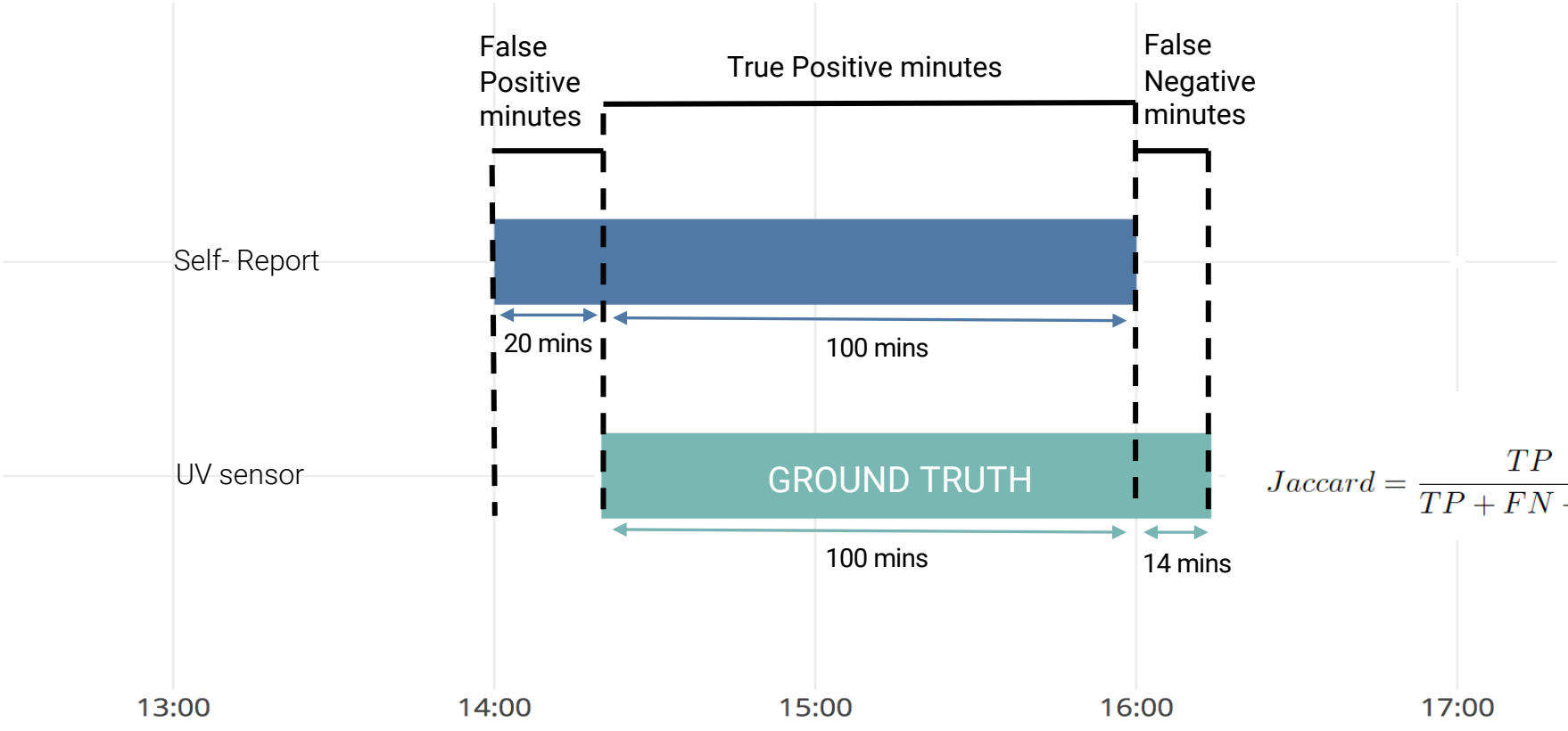
- Fragmentation of UV sensor data



- Filter UV sensor events shorter than minimum duration for self-report

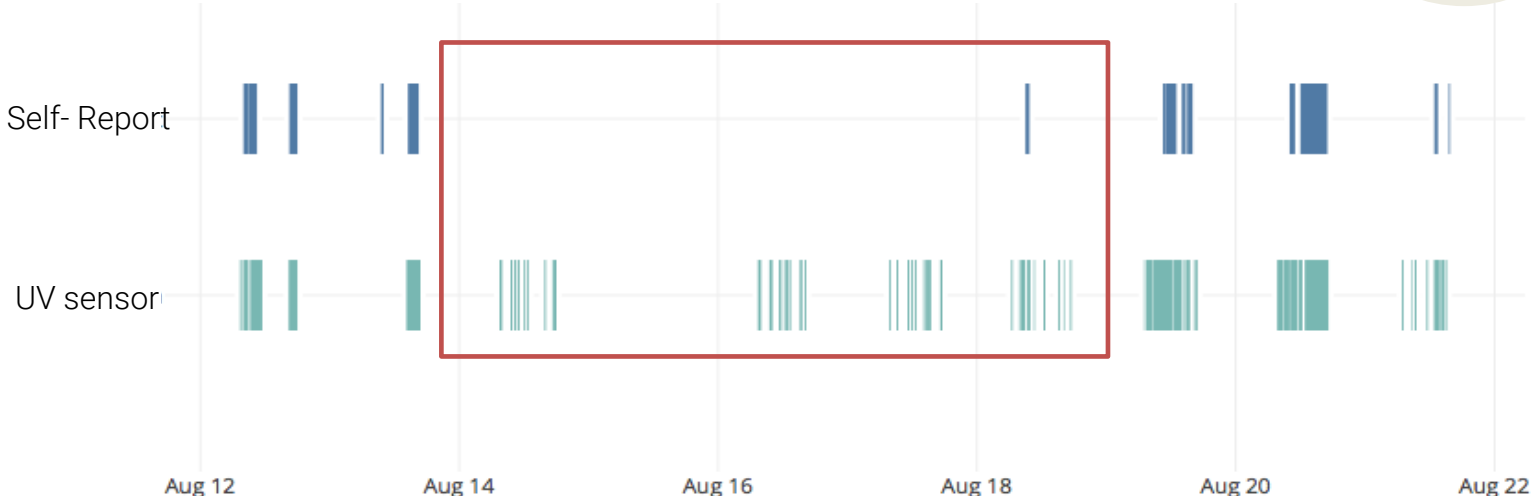

Self- Report
UV Sensor data
Step 1: Filter events < 6mins
Events < 6mins filtered out
Step 2: Density Clustering (Max gap = 6mins)
Events separated by at most 6mins are combined to one event
Step 3: Filter events < 15mins
Events < 15mins filtered out
08:00
10:00
12:00
14:00
16:00
18:00

Metrics

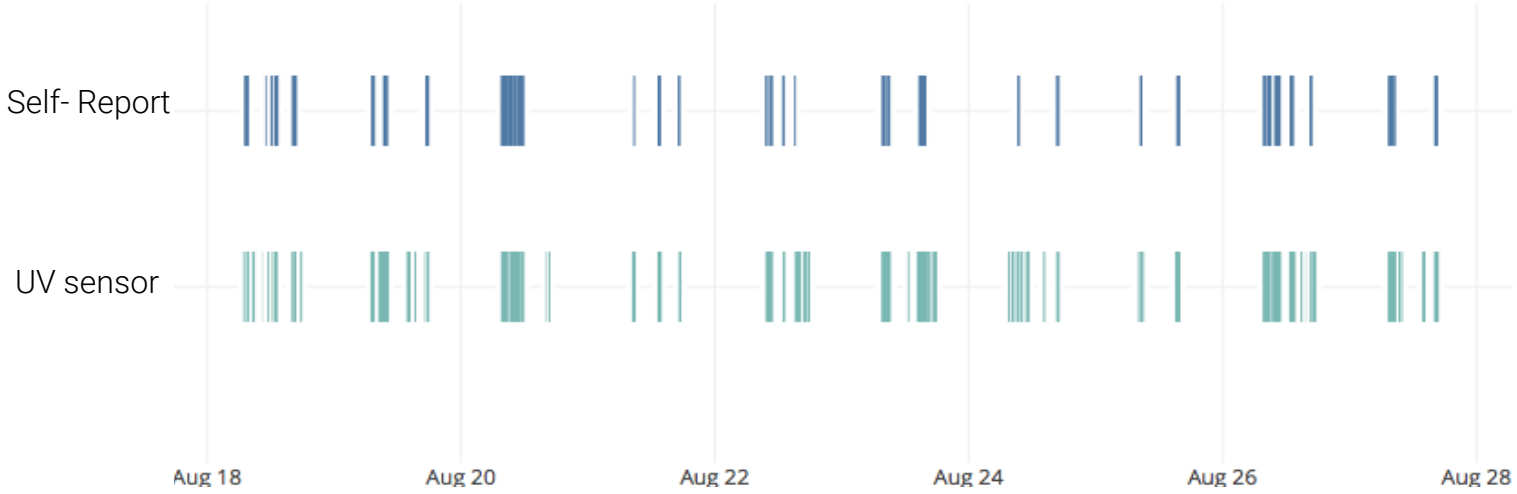


$$Jaccard = \frac{TP}{TP + FN + FP}$$

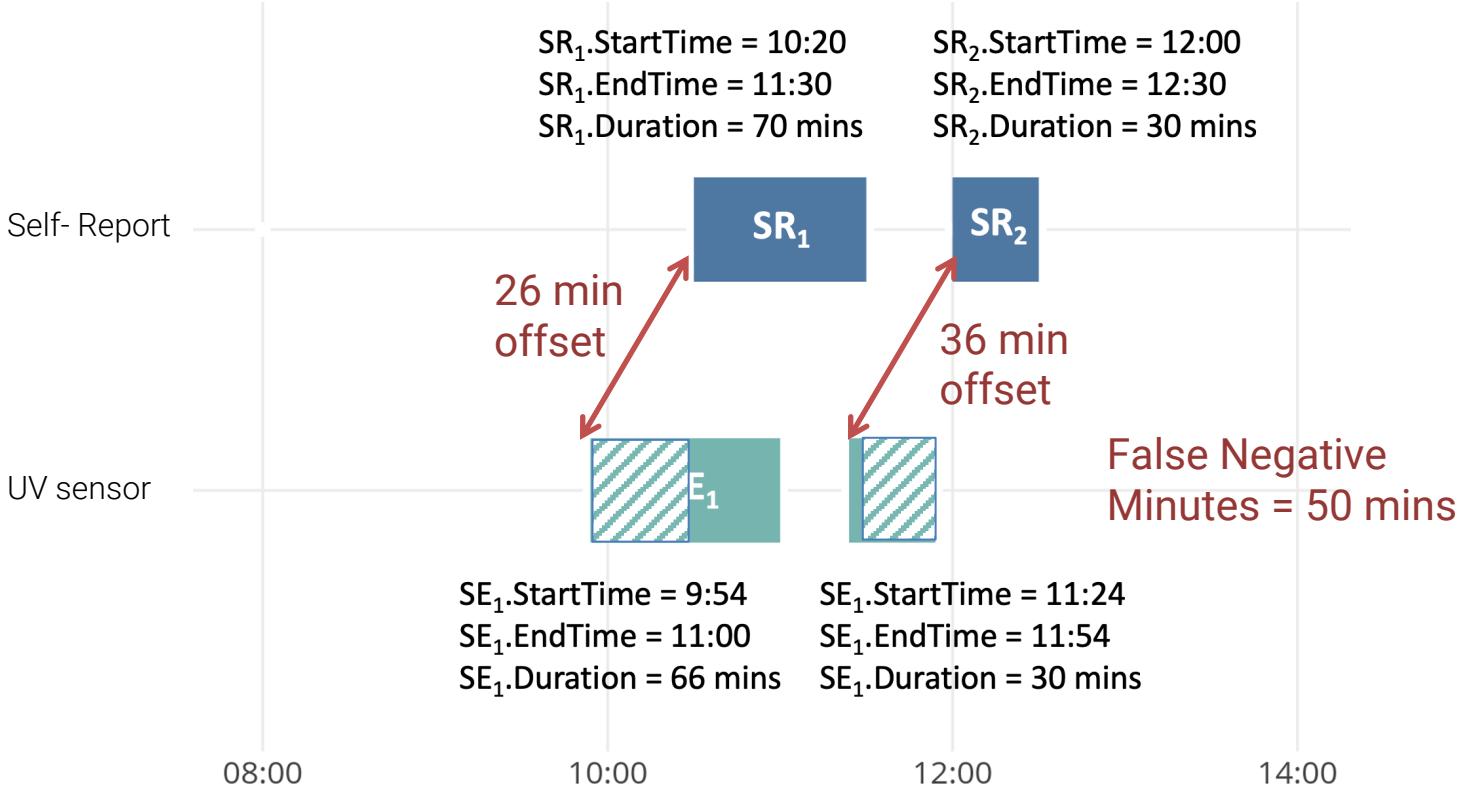
Jaccard coeff. 0.28



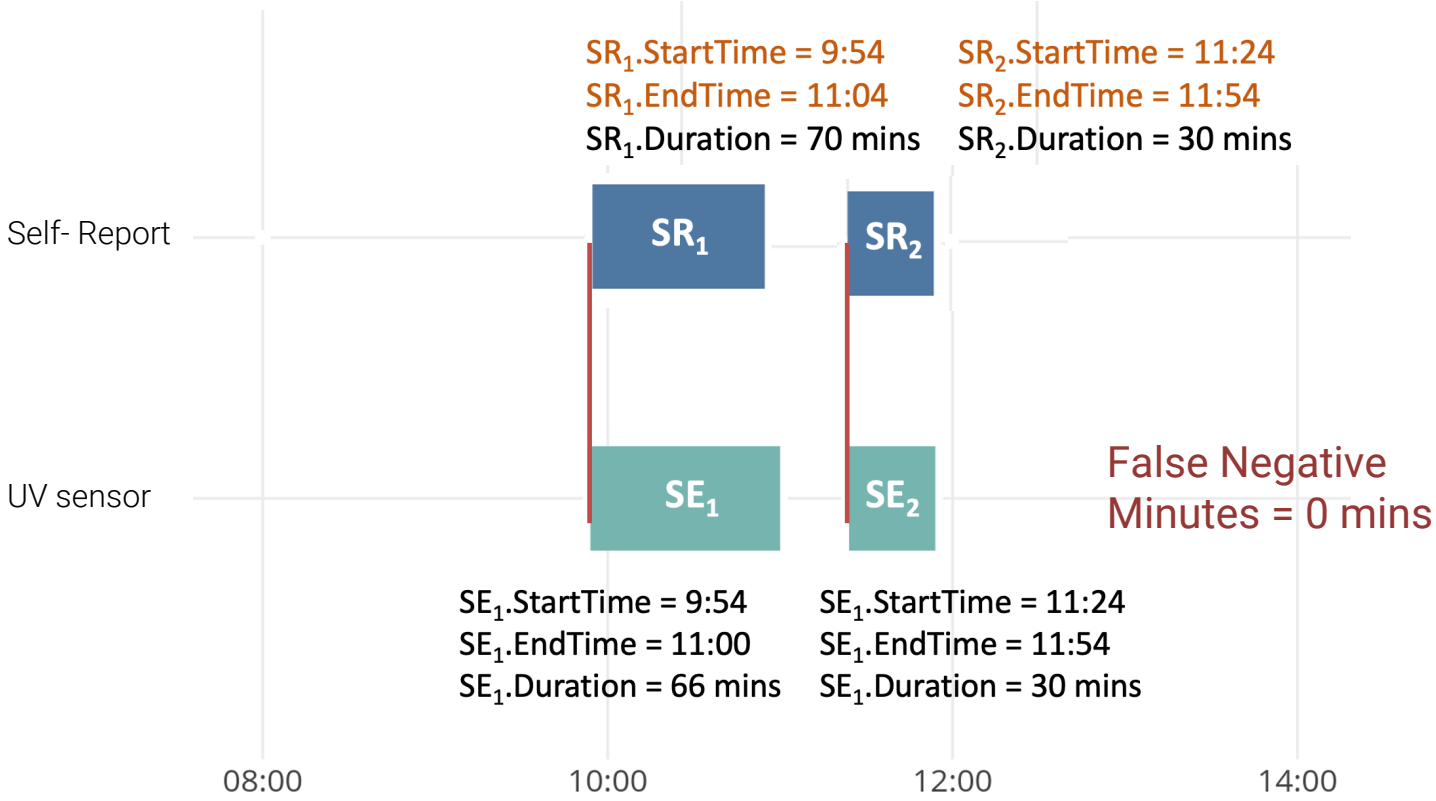
Jaccard coeff.
0.64



Alignment


SR_1.StartTime = 10:20
SR_1.EndTime = 11:30
SR_1.Duration = 70 mins
SR_2.StartTime = 12:00
SR_2.EndTime = 12:30
SR_2.Duration = 30 mins
Self- Report
SR_1
SR_2
26 min offset
36 min offset
UV sensor
E_1
False Negative Minutes = 50 mins
SE_1.StartTime = 9:54
SE_1.EndTime = 11:00
SE_1.Duration = 66 mins
SE_1.StartTime = 11:24
SE_1.EndTime = 11:54
SE_1.Duration = 30 mins
08:00
10:00
12:00
14:00

Alignment


SR_1.StartTime = 9:54
SR_1.EndTime = 11:04
SR_1.Duration = 70 mins
SR_2.StartTime = 11:24
SR_2.EndTime = 11:54
SR_2.Duration = 30 mins
Self- Report
UV sensor
SR_1
SR_2
SE_1
SE_2
False Negative
Minutes = 0 mins
SE_1.StartTime = 9:54
SE_1.EndTime = 11:00
SE_1.Duration = 66 mins
SE_1.StartTime = 11:24
SE_1.EndTime = 11:54
SE_1.Duration = 30 mins
08:00
10:00
12:00
14:00

Optimizing the solution

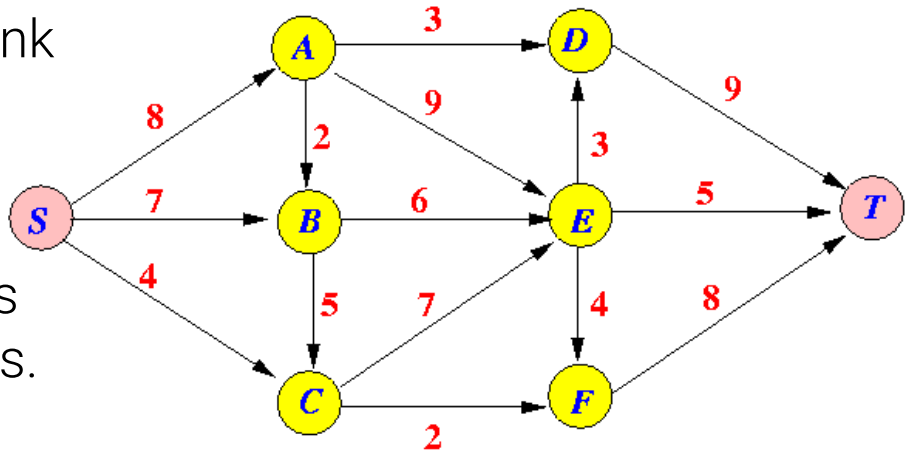
- Exhaustive solution
  - Try every possible combination of self-report and sensor event combination within a day.

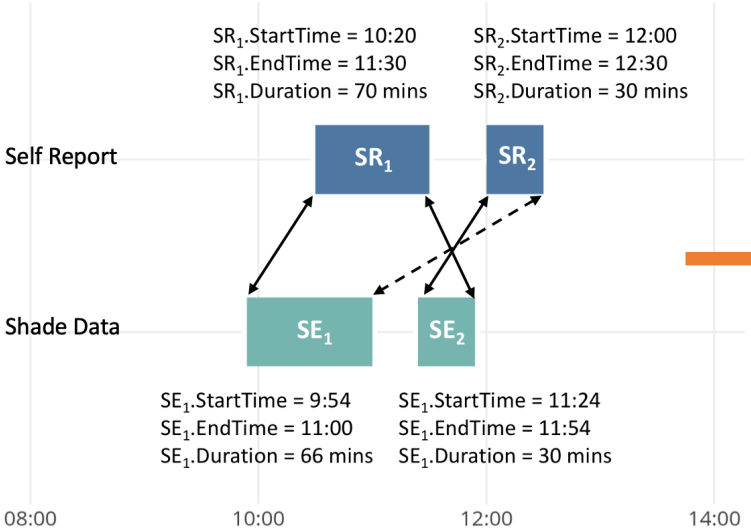
- Bounded exhastive
  - Try all possible combinations within a bounding box.

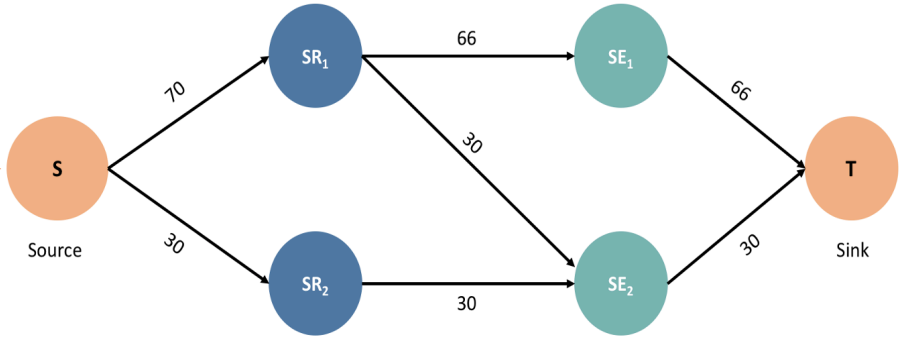
Both these solutions will take a long time to compute given a large number of self-reports.

Network Flow Solution

- Alignment problem = max-flow min-cut problem.
- Find a feasible flow from source to sink such that the flow in the network is maximized
- Flow = number of misaligned minutes to be re-aligned to UV sensor readings.





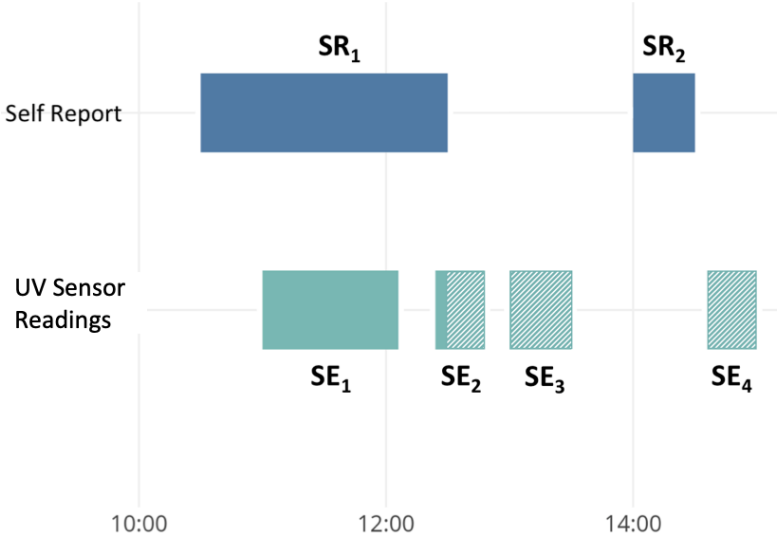


Edge established between SR_i and SE_j since d_{ij} <=md

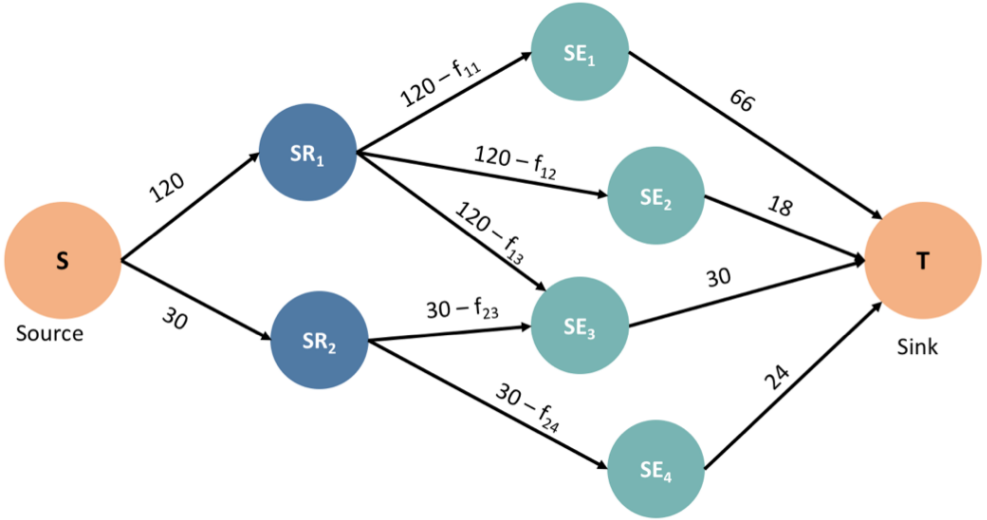
No edge established between SR_i and SE_j since d_{ij}>md

Edmonds- Karps algorithm

Before Alignment

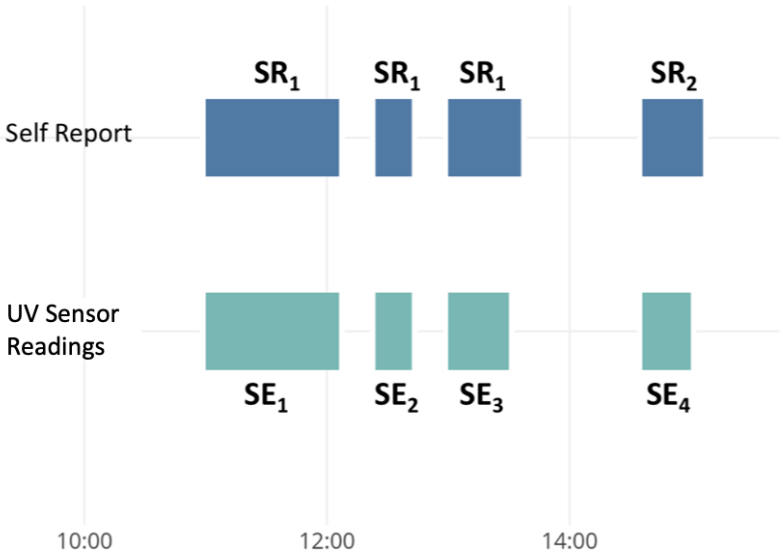


False negatives = 108 mins

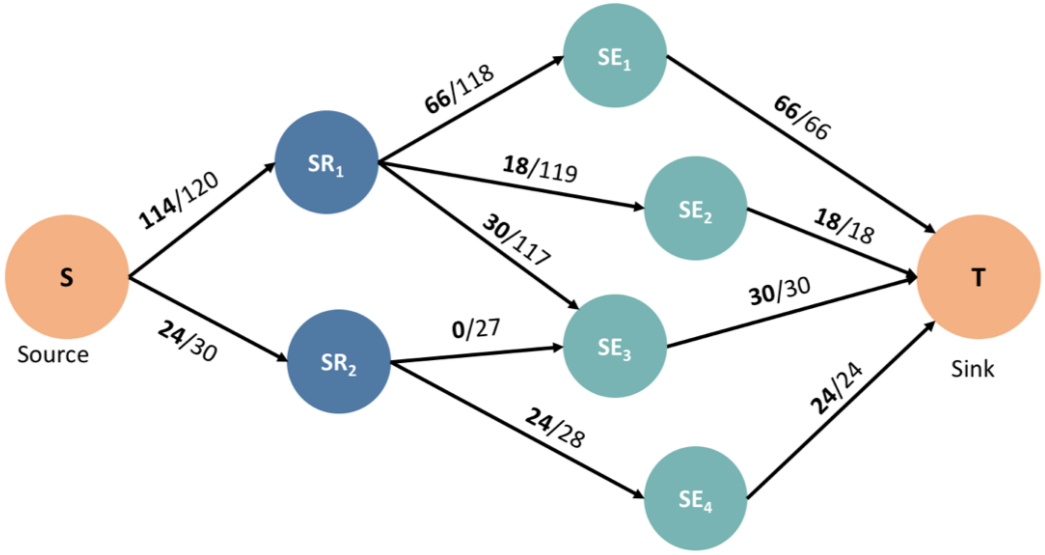


$f_{ij} = Cd_{ij}$
where C is a constant, 0 <= C <= 1
d is min(displacement in start times, displacement in end times) between the start of SR_i and SE_j

After Alignment



False negatives = 0 mins



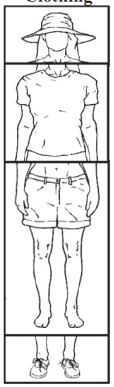
C = 0.05
d_{11} = 24, d_{12} = 18, d_{13} = 60, d_{23} = 60, d_{24} = 30

Protection Adjusted UV Dose

Example Scenario

Yard Work – 9 AM - 1 PM

Clothing



Additional options

- No use of gloves, scarf, umbrella, sunglasses
- No shade use
- Did not sweat or get wet
- Sunscreen not applied

Variations

Variation 1 – Clothing
- Long sleeves, gloves, long pants worn

Variation 2 – Shade
- Shade use reported all the time

Variation 3 – Sunscreen 1
- Sunscreen applied at 9 AM and again at 11 AM to face, arms, legs

Variation 4 – Sunscreen 2
- Sunscreen applied at 9 AM to face, arms, legs, and no subsequent application

MUSE Metrics from Example Scenario and Variations (Var.)

	Example Scenario	Var. 1 - Clothing	Var. 2 – Shade	Var. 3 – Sunscreen 1	Var. 4 – Sunscreen 2
Overall MUSE	92.4	0	0	0	46.2
Time Outdoors (minutes)	240	240	240	240	240
Average % Body Exposed	38.5%	0%	0%	0%	19.25%
Sun-Protection Behavior Percentage					
Brimmed Hat	100%	100%	100%	100%	100%
Shirt with Sleeves	100%	100%	100%	100%	100%
Sunglasses	0%	0%	0%	0%	0%
Sunscreen	0%	0%	0%	100%	50%
Shade	0%	0%	100%	0%	0%
Body-Site MUSE (minutes exposed)					
Scalp	0	0	0	0	0
Upper Face	0	0	0	0	0
Lower Face	0	0	0	0	0
Ears	0	0	0	0	0
Neck	0	0	0	0	0
Shoulders	0	0	0	0	0
Upper Arm	240	0	0	0	120
Forearms	240	0	0	0	120
Hands	240	0	0	0	120
Chest	0	0	0	0	0
Abdomen	0	0	0	0	0
Back	0	0	0	0	0
Thighs	0	0	0	0	0
Knee Area	240	0	0	0	120
Calves Area	240	0	0	0	120
Ankle Area	240	0	0	0	120
Feet	0	0	0	0	0

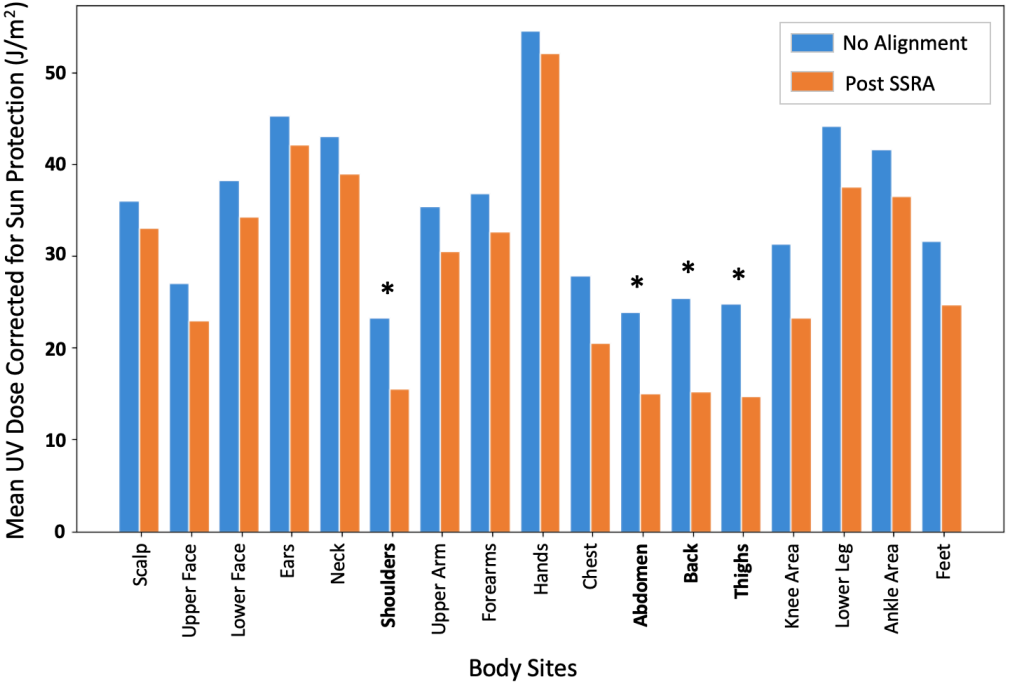
Results

Comparision of alignment solutions

Alignment Solutions	Run time (in secs)	Runtime complexity	Avg. False Negative minutes	Avg. Jaccard
Exhaustive	19.18	O(m! + mn)	57.54	0.27
Bounded Exhaustive	9.5	O(m! + mn)	58.53	0.25
Network Flow	**4.6**	**$O(VE^2)$**	**55.59**	**0.29**

Results

Mean UV corrected for sun protection per body site



Results

Sun Exposure Metrics

	No Alignment	Post SSRA framework
Jaccard	0.18 *	0.29 *
False Negative minutes	83.65 *	55.51 *
False Positive minutes	33.88	27.92

Results

Outdoor Physical Minutes

	No Alignment	Post SSRA framework
Sedentary minutes	38.21 *	25.19 *
Light minutes	30.56 *	22.97 *
Moderate minutes	9.68	27.92
Vigorous minutes	0.16	0.14

Conclusion

- SSRA framework helps improve alignment between self-report and sensor data.
- Helps us improve our understanding of personal UV sensor exposure and its effect in population settings
- Our results show how without alignment, sun exposure times and physical activity estimates are inaccurate
- Merging sensor and self-report measures significantly improves our understanding of health behaviors.