

Robust Relational Layout Synthesis from Examples



Pavol Bielik, Marc Fischer, Martin Vechev

Department of Computer Science
ETH Zurich

User Interface Design Today

Developer →



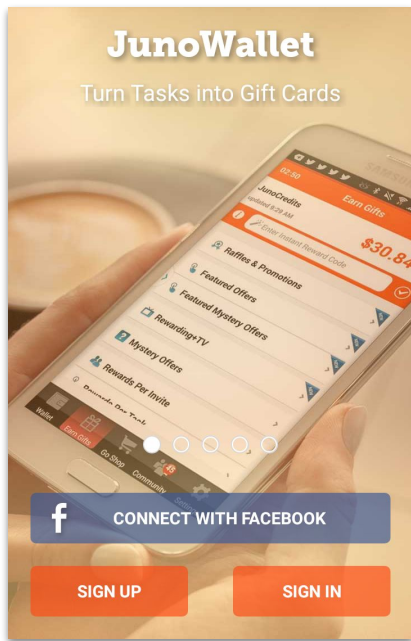
← Designer

picture created by



[Credits: [Radu Cristian](#)]

- Components
 - Sliders
 - App Icons
 - Tab Bars
 - Table Cells
 - iMessage Thread
 - Today 1:20P...
 - iMessage
 - Message Ri...
 - Message Ri...
 - Message Left
 - Text
 - Bubble
 - B...
 - Delivered
 - Typing Indic...
 - Background
 - iMessage
 - Table Cell - ...
 - Table Cell
 - Hairline
 - Dean H...
 - Dinner ...
 - Glyph - ...



X 765 Y 1530
W 254 H 55
b. 180° r 17

CONSTRAINTS



LAYER

Pass Through 100%

FILL

#DADADA 100%

STROKE

EFFECTS

EXPORT

Click + to add an export setting

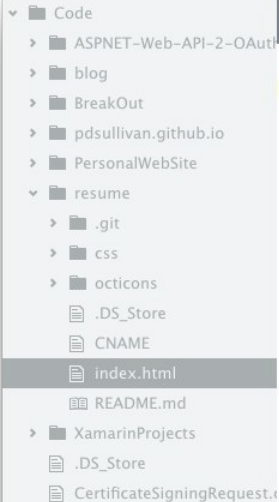
Designer

- Code
- ASPNET-Web-API-2-OAuth
- blog
- BreakOut
- pdsullivan.github.io
- PersonalWebSite
- resume
 - .git
 - css
 - octicons
 - .DS_Store
 - CNAME
 - index.html
 - README.md
- XamarinProjects
 - .DS_Store
 - CertificateSigningRequest.

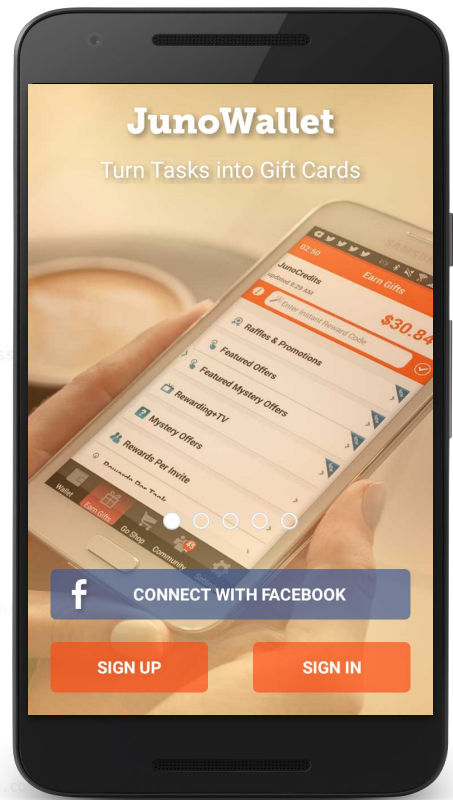
```

1 <!DOCTYPE html>
2 <html>
3 |
4 <head>
5     <meta charset="utf-8" />
6     <meta http-equiv="X-UA-Compatible" content="chrome=1" />
7     <meta name="description" content="Resume : resume" />
8     <meta name="viewport" content="width=device-width, initial-scale=1.0" />
9     <link rel="stylesheet" href="http://maxcdn.bootstrapcdn.com/bootstrap/3.2.0/css/bootstrap.min.css">
10    <link rel="stylesheet" href="http://maxcdn.bootstrapcdn.com/bootstrap/3.2.0/css/bootstrap-theme.min.css">
11    <link rel="stylesheet" href="css/stylesheet.css">
12    <link rel="stylesheet" href="octicons/octicons.css">
13    <script src="https://ajax.googleapis.com/ajax/libs/jquery/1.11.1/jquery.min.js"></script>
14
15    <script src="http://maxcdn.bootstrapcdn.com/bootstrap/3.2.0/js/bootstrap.min.js"></script>
16
17    <title>Patrick Sullivan - Resume</title>
18 </head>
19
20 <body>
21     <div class="container">
22
23         <!--title row-->
24         <div class="row section-row" >
25             <div class="col-md-8">
26
27                 <h1>
29                 </h1>
30                 <h1>Patrick D. Sullivan <br/>
31                 <small class="lead">Software Engineer | Application Developer</small>
32             </div>
33
34             <div class="col-md-4 text-right hidden-xs">
35                 <h4>
36                 <span class="octicon octicon-mail"></span>
37                 <a class="email" href="mailto:patrick@pdsullivan.com">patrick@pdsullivan.com</a>
38             </h4>
39
40             <h4><span class="octicon octicon-link"></span><a href="http://pdsullivan.com" target="_blank"> pdsullivan.com</a></h4>
41             <h4><span class="octicon octicon-device-mobile"></span> (205)222-4749</h4>
42         </div>
43
44         <div class="col-md-4 visible-xs">
45             <h4>
46             <span class="octicon octicon-mail"></span>
47             <a class="email" href="mailto:patrick@pdsullivan.com">patrick@pdsullivan.com</a>
48         </h4>
49
50             <h4><span class="octicon octicon-link"></span><a href="http://pdsullivan.com" target="_blank"> pdsullivan.com</a></h4>
51             <h4><span class="octicon octicon-device-mobile"></span> (205)222-4749</h4>
52         </div>
53
54     </div>
55

```

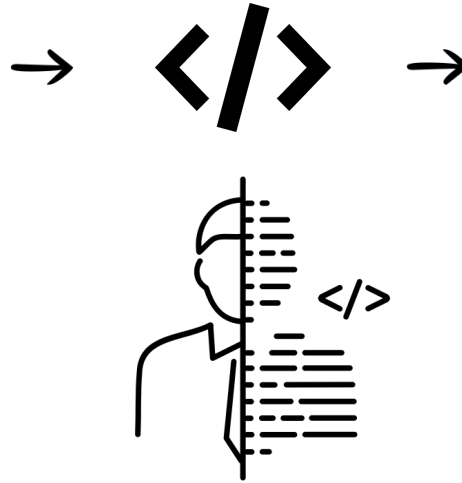
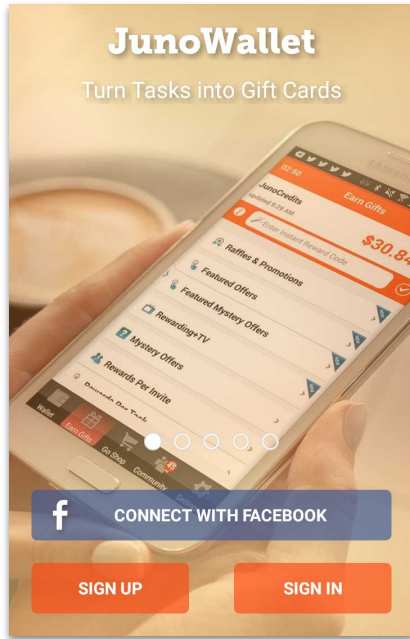


```
1 <!DOCTYPE html>
2 <html>
3
4 <head>
5
6 <meta charset="utf-8" />
7 <meta http-equiv="X-UA-Compatible" content="IE=edge" />
8 <meta name="viewport" content="width=device-width, initial-scale=1" />
9
10 <!-- iOS and Android meta tags -->
11
12 <!-- Windows logo -->
13
14 <!-- Bootstrap CSS -->
15 <link rel="stylesheet" href="https://maxcdn.bootstrapcdn.com/bootstrap/3.2.0/css/bootstrap.min.css">
16 <link rel="stylesheet" href="https://maxcdn.bootstrapcdn.com/bootstrap/3.2.0/css/bootstrap-theme.min.css">
17
18 <!-- Octicons -->
19 <link rel="stylesheet" href="https://cdnjs.cloudflare.com/ajax/libs/octicons/3.2.0/octicons.min.css">
20
21 <!-- jQuery -->
22 <script src="https://ajax.googleapis.com/ajax/libs/jquery/1.11.1/jquery.min.js"></script>
23
24 <!-- Bootstrap JS -->
25 <script src="https://maxcdn.bootstrapcdn.com/bootstrap/3.2.0/js/bootstrap.min.js"></script>
26
27 </head>
28
29 <body class="antialiased">
30
31 <div class="row section-row">
32 <div class="col-md-8">
33
34 <div class="row">
35 <div class="col-sm-2 col-md-3">
36 <img alt="TK logo" data-bbox="235 300 295 405"/>
37
38 <div class="col-sm-2 col-md-3">
39 <img alt="Qt logo" data-bbox="310 310 375 395"/>
40
41 <div class="col-sm-2 col-md-3">
42 <img alt="JavaFX logo" data-bbox="390 315 485 385"/>
43
44 <div class="col-sm-2 col-md-3">
45 <img alt="WPF logo" data-bbox="505 295 575 385"/>
46
47 </div>
48
49 <div class="row">
50 <div class="col-sm-2 col-md-3">
51 <img alt="Foundation ZURB logo" data-bbox="225 475 355 535"/>
52
53 <div class="col-sm-2 col-md-3">
54 <img alt="Skeleton logo" data-bbox="375 475 525 535"/>
55 <span data-bbox="420 480 525 530">Skeleton  
A dead simple, responsive boilerplate.
56
57 <div class="col-sm-2 col-md-3">
58 <img alt="Cardinal logo" data-bbox="545 490 590 545"/>
59 <span data-bbox="530 545 605 575">Cardinal
60
61 <div class="col-sm-2 col-md-3">
62 <img alt="unsemantic logo" data-bbox="275 560 405 595"/>
63
64 <div class="col-sm-2 col-md-3">
65 <img alt="Onsen UI logo" data-bbox="440 560 485 655"/>
66 <span data-bbox="440 635 485 655">Onsen UI
67
68 <div class="col-sm-2 col-md-3">
69 <img alt="Pure.CSS logo" data-bbox="205 605 390 670"/>
70 <span data-bbox="280 625 390 665">Pure.CSS
71
72 <div class="col-sm-2 col-md-3">
73 <img alt="Materialize logo" data-bbox="245 705 295 760"/>
74 <span data-bbox="240 775 300 795">Materialize
75
76 <div class="col-sm-2 col-md-3">
77 <img alt="UIKit logo" data-bbox="315 695 405 765"/>
78 <span data-bbox="355 715 405 745">UIKit
79
80 <div class="col-sm-2 col-md-3">
81 <img alt="Bootstrap logo" data-bbox="490 665 525 725"/>
82 <span data-bbox="475 725 535 750">Bootstrap
83
84 <div class="col-sm-2 col-md-3">
85 <img alt="INK logo" data-bbox="555 700 615 745"/>
86 <span data-bbox="560 705 615 745">INK
87
88 <div class="col-sm-2 col-md-3">
89 <img alt="GroundworkCSS 2 logo" data-bbox="335 775 375 835"/>
90 <span data-bbox="375 785 495 805">GroundworkCSS 2
91
92 <div class="col-sm-2 col-md-3">
93 <img alt="BULMA logo" data-bbox="510 770 535 810"/>
94 <span data-bbox="535 770 605 805">BULMA
95
96 </div>
97
98 </div>
99
100 </div>
101
102 </div>
103
104 </div>
105
106 </div>
107
108 </div>
109
110 </div>
111
112 </div>
113
114 </div>
115
116 </div>
117
118 </div>
119
120 </div>
121
122 </div>
123
124 </div>
125
126 </div>
127
128 </div>
129
130 </div>
131
132 </div>
133
134 </div>
135
136 </div>
137
138 </div>
139
140 </div>
141
142 </div>
143
144 </div>
145
146 </div>
147
148 </div>
149
150 </div>
151
152 </div>
153
154 </div>
155
156 </div>
157
158 </div>
159
160 </div>
161
162 </div>
163
164 </div>
165
166 </div>
167
168 </div>
169
170 </div>
171
172 </div>
173
174 </div>
175
176 </div>
177
178 </div>
179
180 </div>
181
182 </div>
183
184 </div>
185
186 </div>
187
188 </div>
189
190 </div>
191
192 </div>
193
194 </div>
195
196 </div>
197
198 </div>
199
200 </div>
201
202 </div>
203
204 </div>
205
206 </div>
207
208 </div>
209
210 </div>
211
212 </div>
213
214 </div>
215
216 </div>
217
218 </div>
219
220 </div>
221
222 </div>
223
224 </div>
225
226 </div>
227
228 </div>
229
230 </div>
231
232 </div>
233
234 </div>
235
236 </div>
237
238 </div>
239
240 </div>
241
242 </div>
243
244 </div>
245
246 </div>
247
248 </div>
249
250 </div>
251
252 </div>
253
254 </div>
255
256 </div>
257
258 </div>
259
260 </div>
261
262 </div>
263
264 </div>
265
266 </div>
267
268 </div>
269
270 </div>
271
272 </div>
273
274 </div>
275
276 </div>
277
278 </div>
279
280 </div>
281
282 </div>
283
284 </div>
285
286 </div>
287
288 </div>
289
290 </div>
291
292 </div>
293
294 </div>
295
296 </div>
297
298 </div>
299
300 </div>
301
302 </div>
303
304 </div>
305
306 </div>
307
308 </div>
309
310 </div>
311
312 </div>
313
314 </div>
315
316 </div>
317
318 </div>
319
320 </div>
321
322 </div>
323
324 </div>
325
326 </div>
327
328 </div>
329
330 </div>
331
332 </div>
333
334 </div>
335
336 </div>
337
338 </div>
339
340 </div>
341
342 </div>
343
344 </div>
345
346 </div>
347
348 </div>
349
350 </div>
351
352 </div>
353
354 </div>
355
356 </div>
357
358 </div>
359
360 </div>
361
362 </div>
363
364 </div>
365
366 </div>
367
368 </div>
369
370 </div>
371
372 </div>
373
374 </div>
375
376 </div>
377
378 </div>
379
380 </div>
381
382 </div>
383
384 </div>
385
386 </div>
387
388 </div>
389
390 </div>
391
392 </div>
393
394 </div>
395
396 </div>
397
398 </div>
399
400 </div>
401
402 </div>
403
404 </div>
405
406 </div>
407
408 </div>
409
410 </div>
411
412 </div>
413
414 </div>
415
416 </div>
417
418 </div>
419
420 </div>
421
422 </div>
423
424 </div>
425
426 </div>
427
428 </div>
429
430 </div>
431
432 </div>
433
434 </div>
435
436 </div>
437
438 </div>
439
440 </div>
441
442 </div>
443
444 </div>
445
446 </div>
447
448 </div>
449
450 </div>
451
452 </div>
453
454 </div>
455
456 </div>
457
458 </div>
459
460 </div>
461
462 </div>
463
464 </div>
465
466 </div>
467
468 </div>
469
470 </div>
471
472 </div>
473
474 </div>
475
476 </div>
477
478 </div>
479
480 </div>
481
482 </div>
483
484 </div>
485
486 </div>
487
488 </div>
489
490 </div>
491
492 </div>
493
494 </div>
495
496 </div>
497
498 </div>
499
500 </div>
501
502 </div>
503
504 </div>
505
506 </div>
507
508 </div>
509
510 </div>
511
512 </div>
513
514 </div>
515
516 </div>
517
518 </div>
519
520 </div>
521
522 </div>
523
524 </div>
525
526 </div>
527
528 </div>
529
530 </div>
531
532 </div>
533
534 </div>
535
536 </div>
537
538 </div>
539
540 </div>
541
542 </div>
543
544 </div>
545
546 </div>
547
548 </div>
549
550 </div>
551
552 </div>
553
554 </div>
555
556 </div>
557
558 </div>
559
560 </div>
561
562 </div>
563
564 </div>
565
566 </div>
567
568 </div>
569
570 </div>
571
572 </div>
573
574 </div>
575
576 </div>
577
578 </div>
579
580 </div>
581
582 </div>
583
584 </div>
585
586 </div>
587
588 </div>
589
590 </div>
591
592 </div>
593
594 </div>
595
596 </div>
597
598 </div>
599
600 </div>
601
602 </div>
603
604 </div>
605
606 </div>
607
608 </div>
609
610 </div>
611
612 </div>
613
614 </div>
615
616 </div>
617
618 </div>
619
620 </div>
621
622 </div>
623
624 </div>
625
626 </div>
627
628 </div>
629
630 </div>
631
632 </div>
633
634 </div>
635
636 </div>
637
638 </div>
639
640 </div>
641
642 </div>
643
644 </div>
645
646 </div>
647
648 </div>
649
650 </div>
651
652 </div>
653
654 </div>
655
656 </div>
657
658 </div>
659
660 </div>
661
662 </div>
663
664 </div>
665
666 </div>
667
668 </div>
669
670 </div>
671
672 </div>
673
674 </div>
675
676 </div>
677
678 </div>
679
680 </div>
681
682 </div>
683
684 </div>
685
686 </div>
687
688 </div>
689
690 </div>
691
692 </div>
693
694 </div>
695
696 </div>
697
698 </div>
699
700 </div>
701
702 </div>
703
704 </div>
705
706 </div>
707
708 </div>
709
710 </div>
711
712 </div>
713
714 </div>
715
716 </div>
717
718 </div>
719
720 </div>
721
722 </div>
723
724 </div>
725
726 </div>
727
728 </div>
729
730 </div>
731
732 </div>
733
734 </div>
735
736 </div>
737
738 </div>
739
740 </div>
741
742 </div>
743
744 </div>
745
746 </div>
747
748 </div>
749
750 </div>
751
752 </div>
753
754 </div>
755
756 </div>
757
758 </div>
759
760 </div>
761
762 </div>
763
764 </div>
765
766 </div>
767
768 </div>
769
770 </div>
771
772 </div>
773
774 </div>
775
776 </div>
777
778 </div>
779
780 </div>
781
782 </div>
783
784 </div>
785
786 </div>
787
788 </div>
789
790 </div>
791
792 </div>
793
794 </div>
795
796 </div>
797
798 </div>
799
800 </div>
801
802 </div>
803
804 </div>
805
806 </div>
807
808 </div>
809
810 </div>
811
812 </div>
813
814 </div>
815
816 </div>
817
818 </div>
819
820 </div>
821
822 </div>
823
824 </div>
825
826 </div>
827
828 </div>
829
830 </div>
831
832 </div>
833
834 </div>
835
836 </div>
837
838 </div>
839
840 </div>
841
842 </div>
843
844 </div>
845
846 </div>
847
848 </div>
849
850 </div>
851
852 </div>
853
854 </div>
855
856 </div>
857
858 </div>
859
860 </div>
861
862 </div>
863
864 </div>
865
866 </div>
867
868 </div>
869
870 </div>
871
872 </div>
873
874 </div>
875
876 </div>
877
878 </div>
879
880 </div>
881
882 </div>
883
884 </div>
885
886 </div>
887
888 </div>
889
890 </div>
891
892 </div>
893
894 </div>
895
896 </div>
897
898 </div>
899
900 </div>
901
902 </div>
903
904 </div>
905
906 </div>
907
908 </div>
909
910 </div>
911
912 </div>
913
914 </div>
915
916 </div>
917
918 </div>
919
920 </div>
921
922 </div>
923
924 </div>
925
926 </div>
927
928 </div>
929
930 </div>
931
932 </div>
933
934 </div>
935
936 </div>
937
938 </div>
939
940 </div>
941
942 </div>
943
944 </div>
945
946 </div>
947
948 </div>
949
950 </div>
951
952 </div>
953
954 </div>
955
956 </div>
957
958 </div>
959
960 </div>
961
962 </div>
963
964 </div>
965
966 </div>
967
968 </div>
969
970 </div>
971
972 </div>
973
974 </div>
975
976 </div>
977
978 </div>
979
980 </div>
981
982 </div>
983
984 </div>
985
986 </div>
987
988 </div>
989
990 </div>
991
992 </div>
993
994 </div>
995
996 </div>
997
998 </div>
999
1000 </div>
```

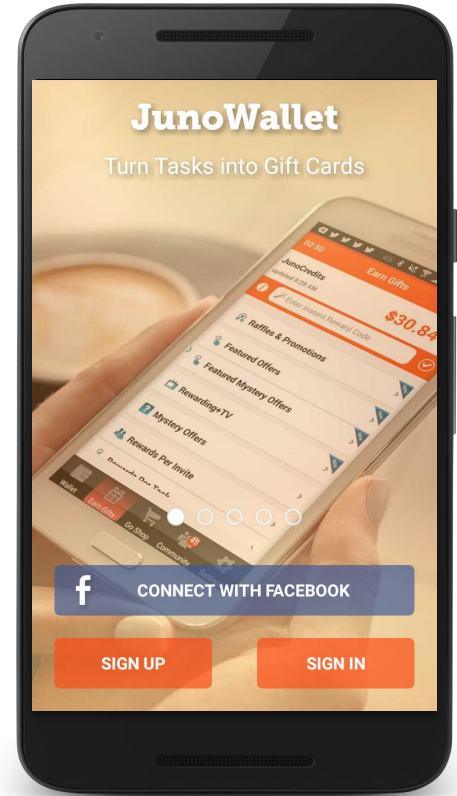


Developer

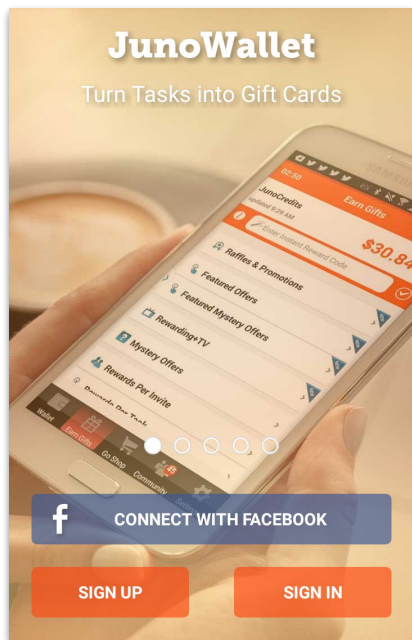
User Interface Design Today



Designer Developer



Our Goal

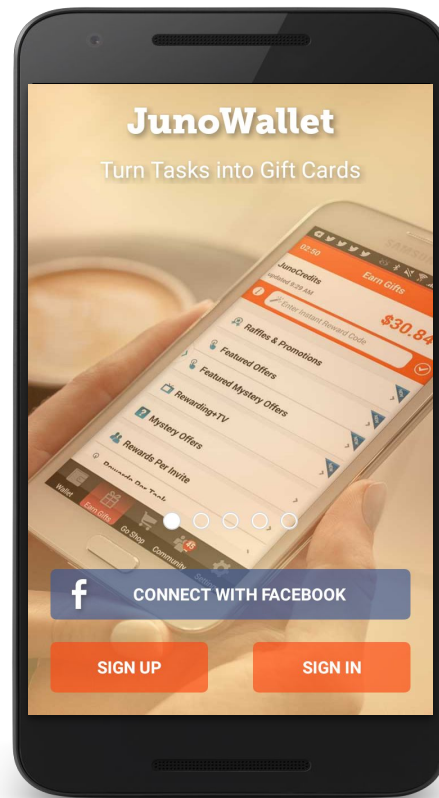


Designer

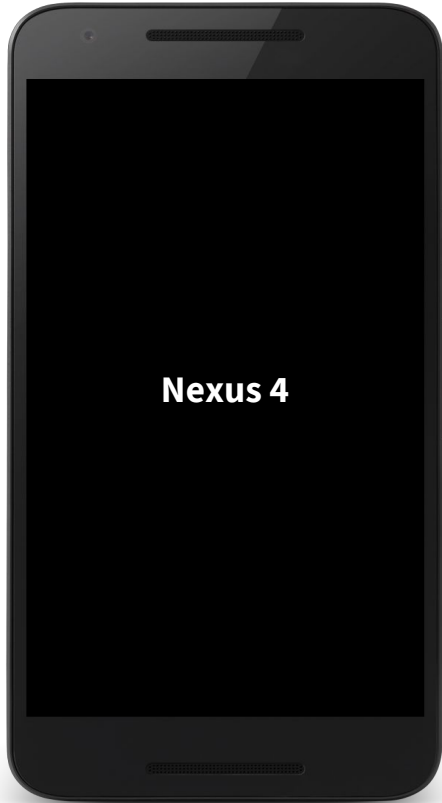


Tool

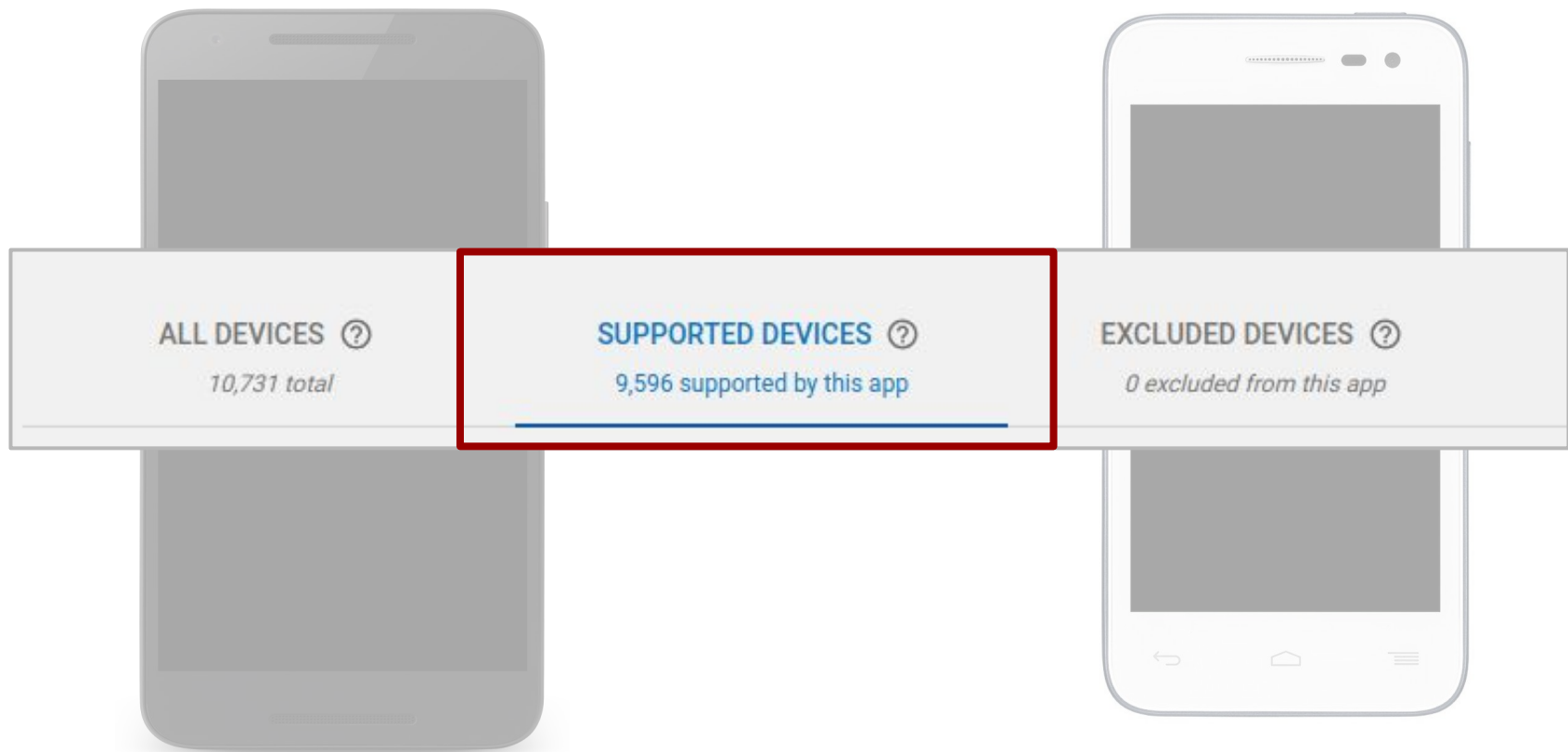
~~Developer~~



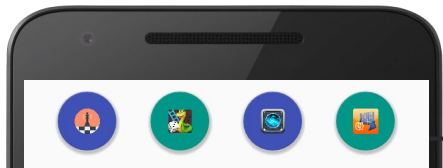
Preventing Layout Errors



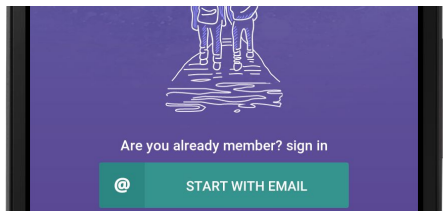
Preventing Layout Errors



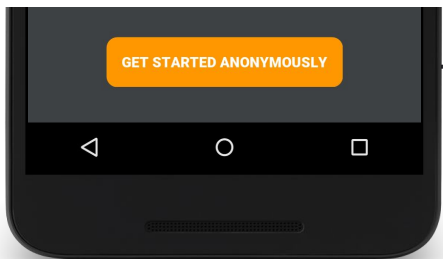
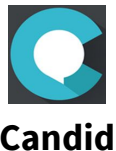
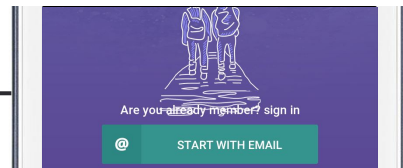
Preventing Layout Errors



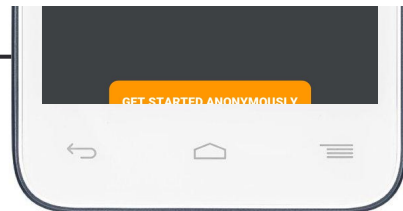
Centering



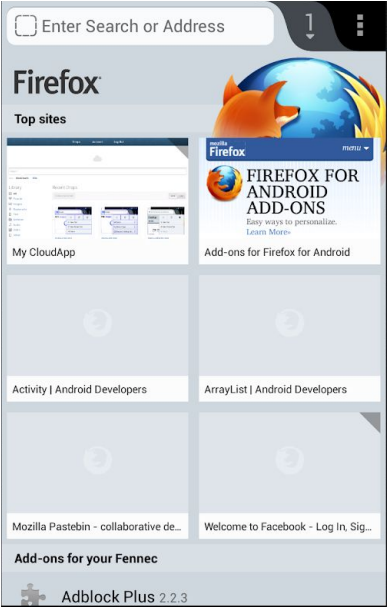
Overlaying Views



Out of Screen



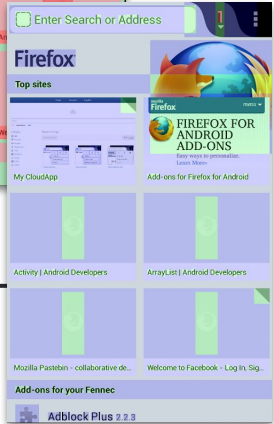
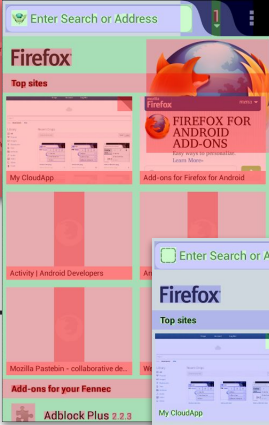
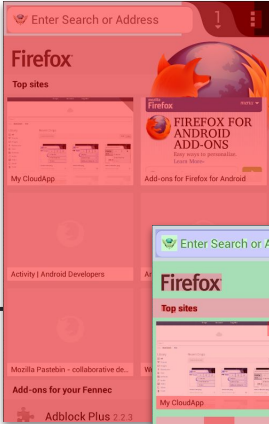
Improving Performance



</>
Layout #1

</>
Layout #2

</>
Layout #3



Slow

Fast

[Credits: [Sriram Ramani](#)]

Code Porting



Linear Layout (horizontal)

Linear Layout (vertical)

Relative Layout



Constraint Layout

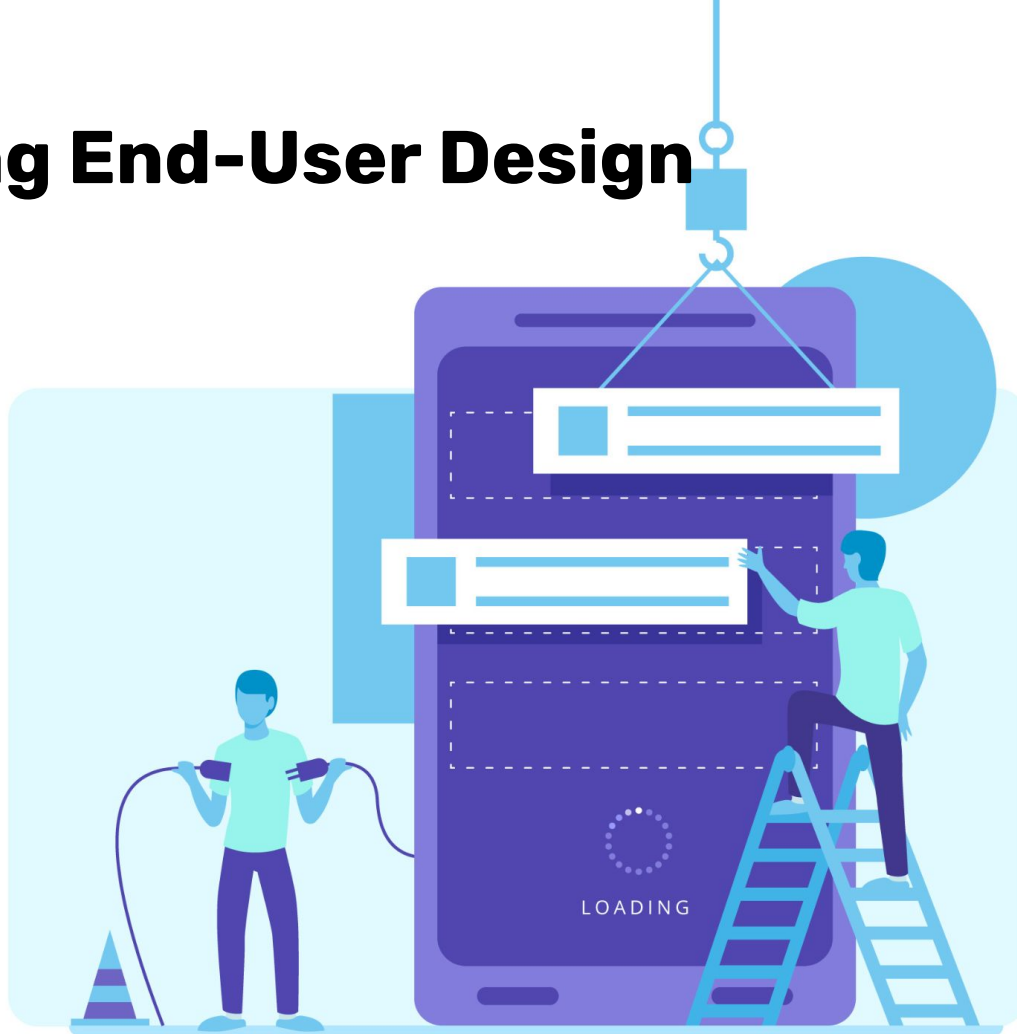
>98%

Old / Deprecated

<2%

Automating End-User Design

Developer →



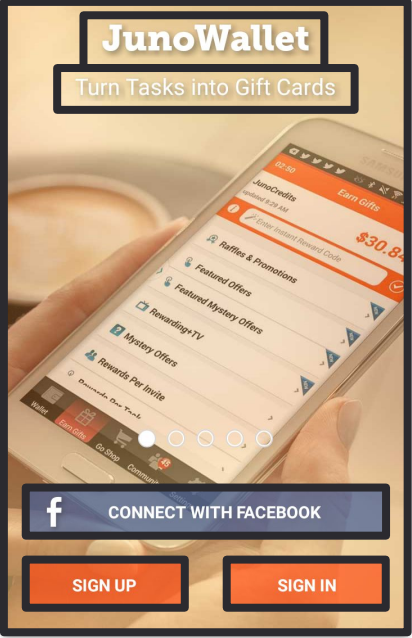
← Designer

picture created by

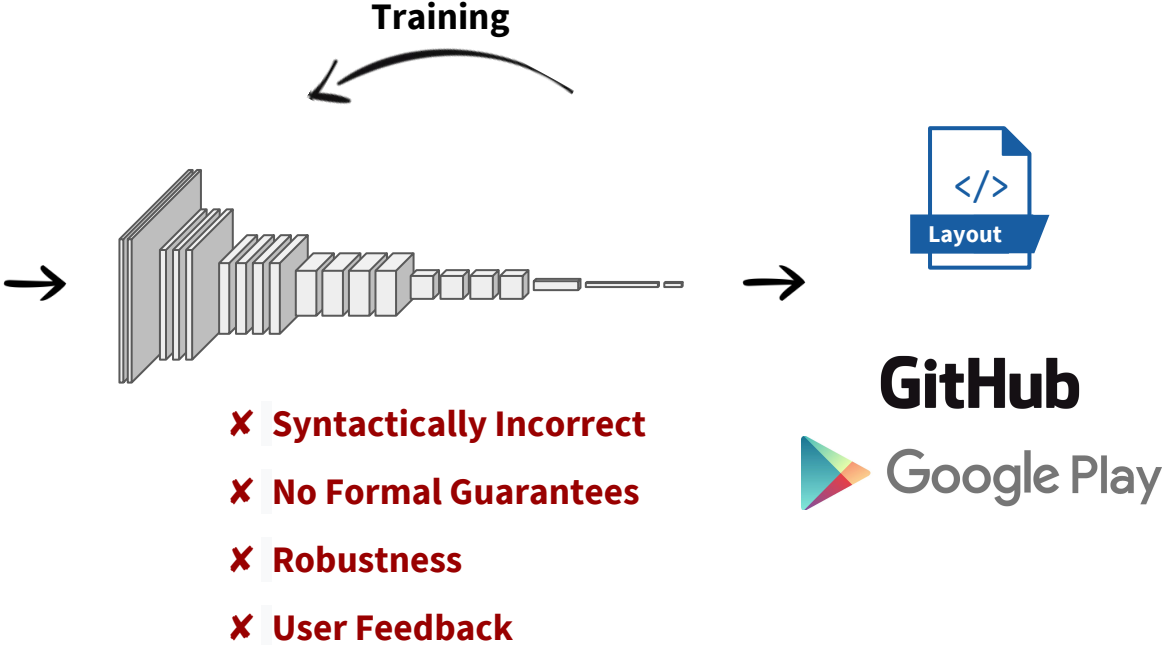


[Credits: [Radu Cristian](#)]

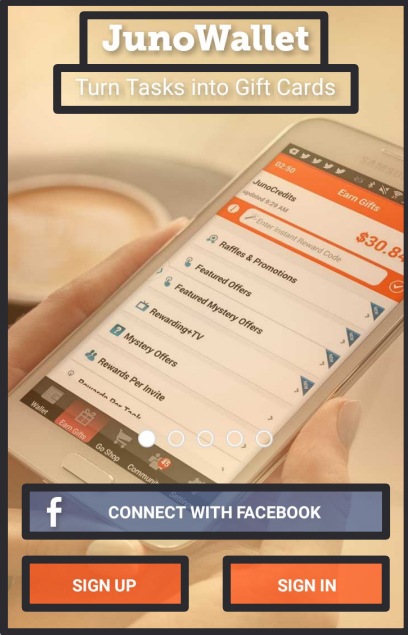
Machine Learning Approach



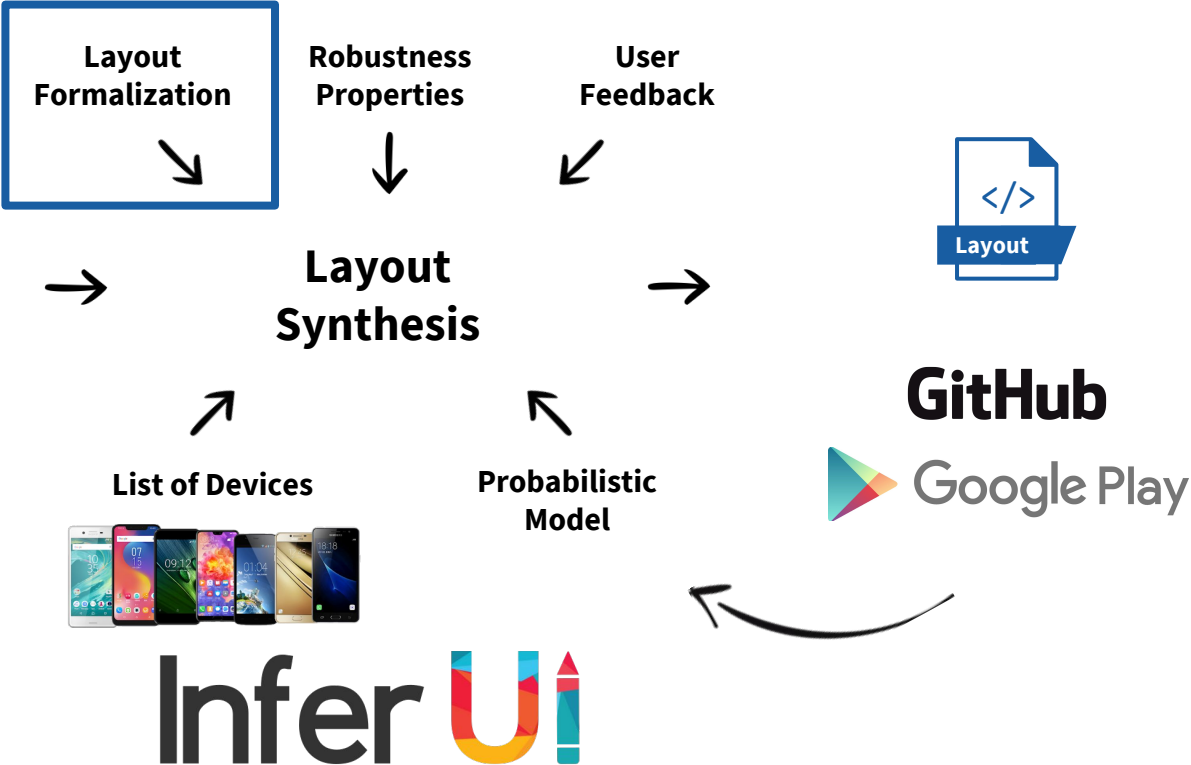
Design Specification



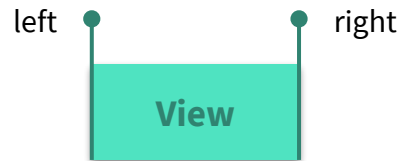
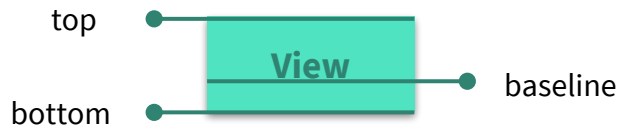
Programming Languages Approach



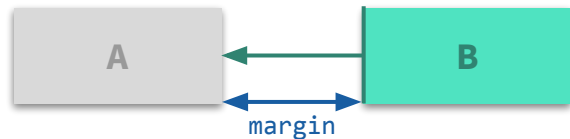
Design Specification



Relational Layout Constraints

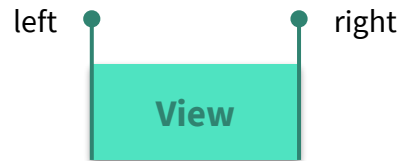


Align left of B to right of A

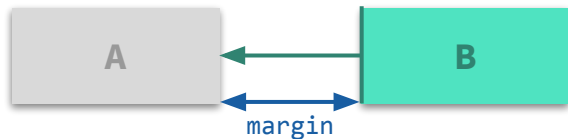


$$B.left = A.right + margin$$

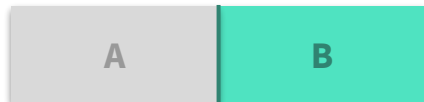
Relational Layout Constraints



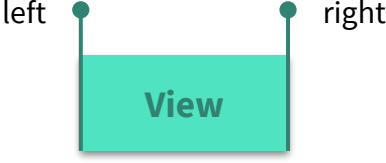
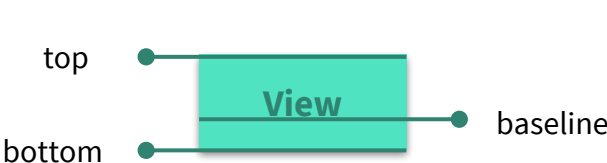
Align left of B to right of A



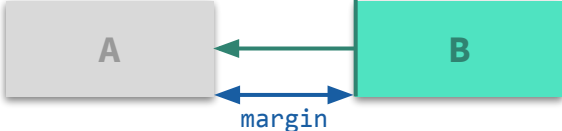
$$B.left = A.right + 0$$



Relational Layout Constraints

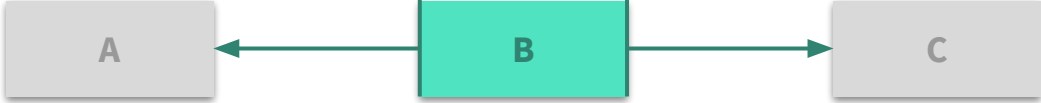


Align left of B to right of A

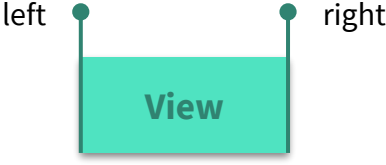
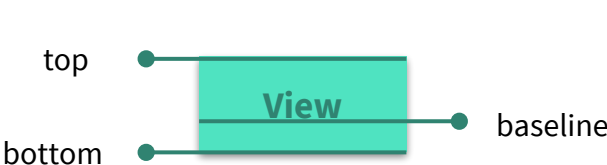


$$B.left = A.right + margin$$

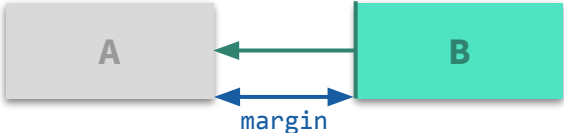
Center B in between right of A and left of C



Relational Layout Constraints

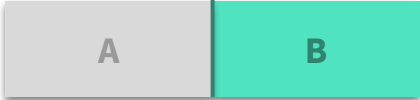


Align left of B to right of A



$$B.left = A.right + margin$$

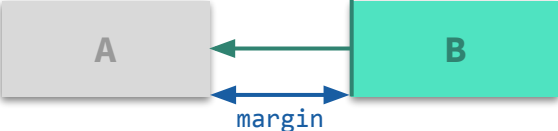
Center B in between right of A and left of C



Relational Layout Constraints

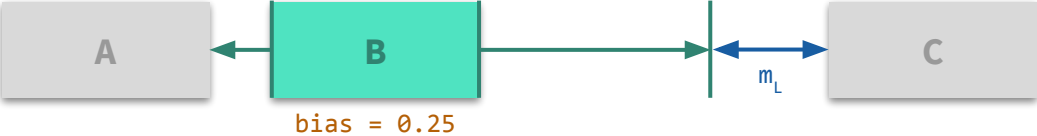


Align left of B to right of A

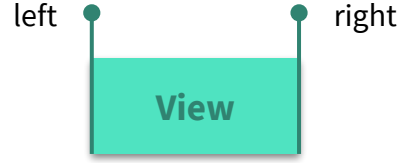
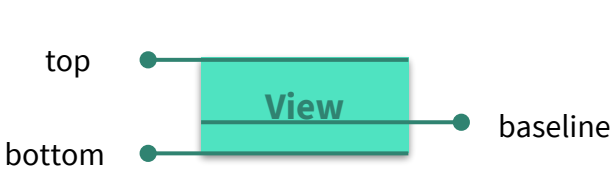


$$B.left = A.right + margin$$

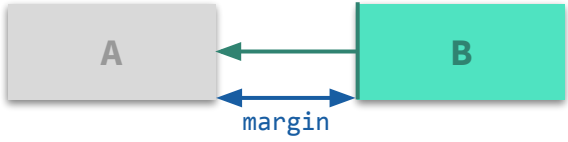
Center B in between right of A and left of C



Relational Layout Constraints

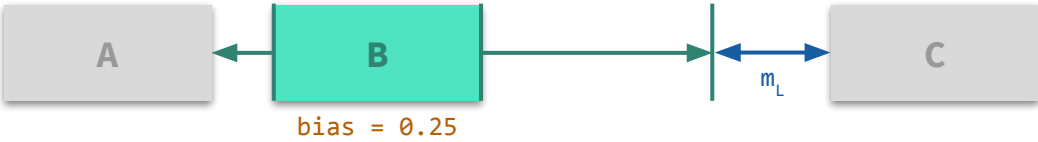


Align left of B to right of A

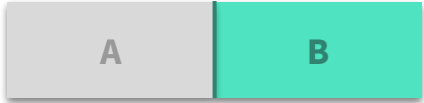
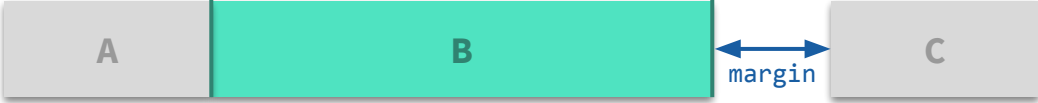


$$B.left = A.right + margin$$

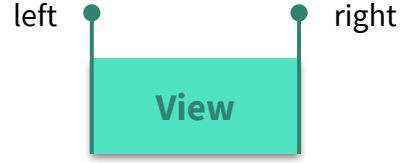
Center B in between right of A and left of C



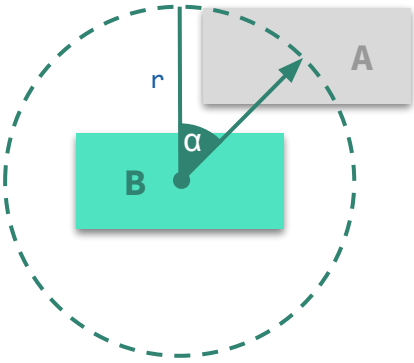
Center B in between right of A and left of C (Dynamic Size)



Relational Layout Constraints



Align Center of A to Center of B at an Angle + Distance



$$B.left + B.right = 2r * \sin(\alpha) + A.left + A.right$$

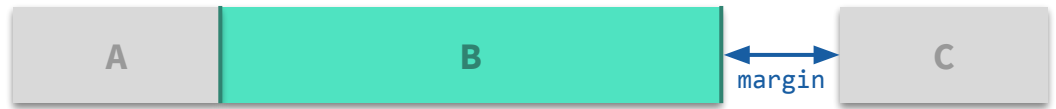
Center B in between right of A and left of C



bias = 0.25

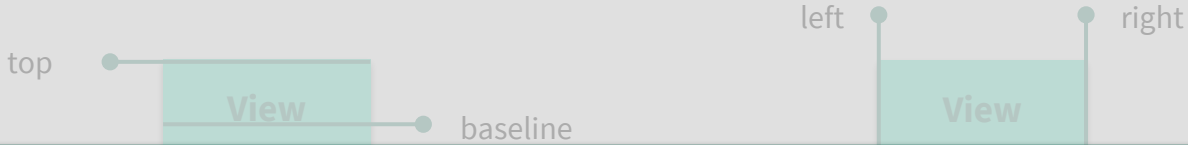
$$(1-b) * B.left + b * B.right = (1-b) * (A.right + m_L) + b * (C.left - m_R)$$

Center B in between right of A and left of C (Dynamic Size)



$$B.left = A.right + m_L \wedge B.right = A.left + m_R$$

Relational Layout Constraints



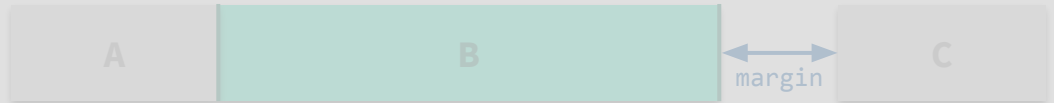
Formalized 26 types of constraints used by the latest Android Constraint Layout

Align Center
at an



$(C.left - m_R)$

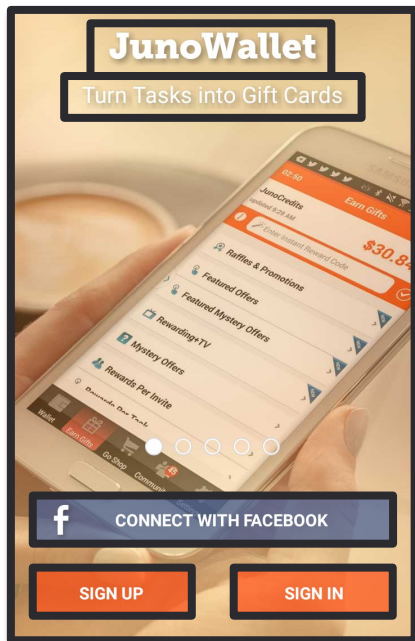
Center B in between right of A and left of C (Dynamic Size)



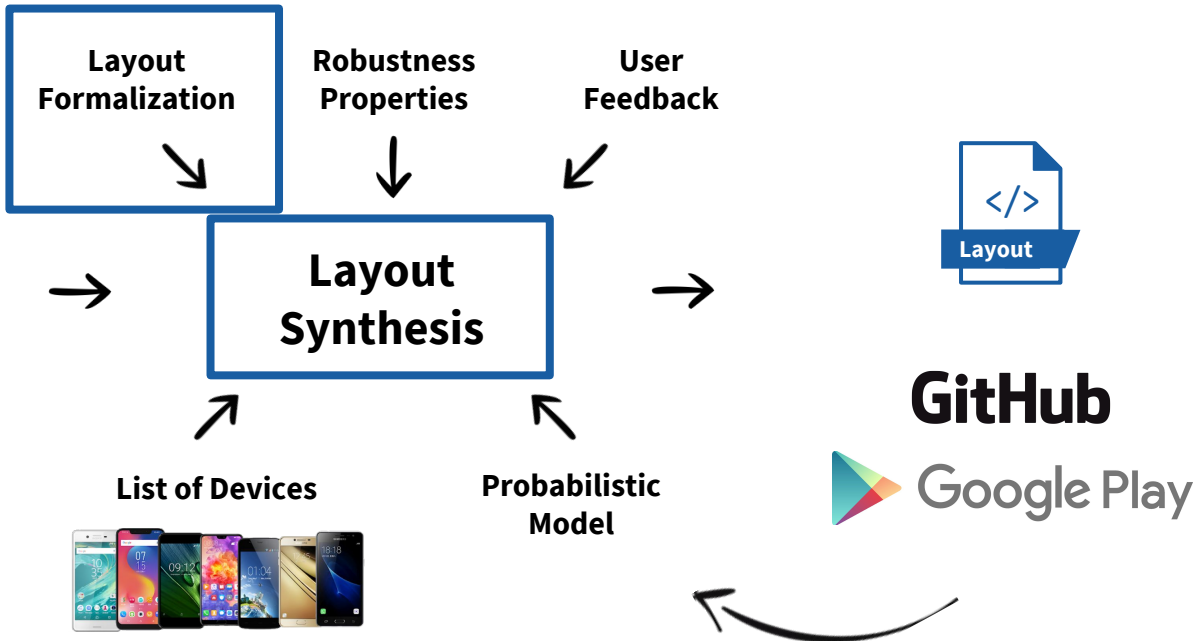
$$B.left + B.right = 2r \cdot \sin(\alpha) + A.left + A.right$$

$$B.left = A.right + m_L \wedge B.right = A.left + m_R$$

Overview



Design Specification

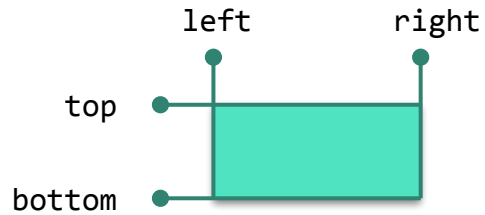


Infer U 

Layout Solving

Goal

Compute absolute position of all the views



Layout Solving

Goal

Compute absolute position of all the views

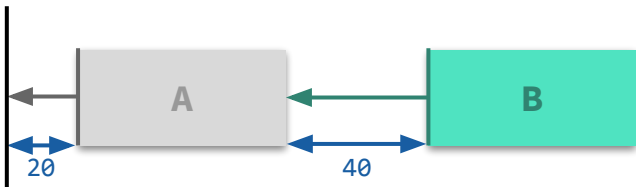
`A.left = ?`

`B.left = ?`

`A.right = ?`

`B.right = ?`

} **v**: Absolute Horizontal Positions



`B.left = A.right + 40`

`A.left = screen.left + 20`

} **c**: Horizontal Position Constraints

`screen.left = 0` \wedge `screen.right = 240`

} **screen**: Target Device

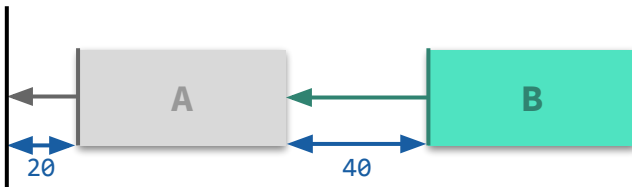
Layout Solving

Goal

Compute absolute position of all the views

```
A.left = 20      B.left = ?  
A.right = ?     B.right = ?
```

} v: Absolute Horizontal Positions



```
B.left = A.right + 40
```

```
A.left = 0 + 20
```

} c: Horizontal Position Constraints

```
screen.left = 0  $\wedge$  screen.right = 240
```

} screen: Target Device

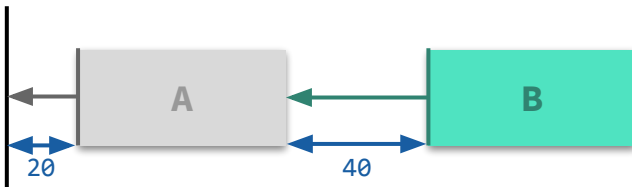
Layout Solving

Goal

Compute absolute position of all the views

```
A.left  = 20      B.left  = 140  
A.right = 100     B.right = 220
```

} **v**: Absolute Horizontal Positions



```
B.left = A.right + 40  
A.left = 0 + 20
```

} **c**: Horizontal Position Constraints

```
screen.left = 0  $\wedge$  screen.right = 240
```

} screen: Target Device

```
A.right - A.left = 80  
B.right - B.left = 80
```

} **s**: Horizontal Size Constraints

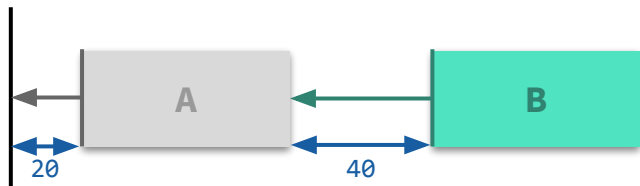
$\mathbf{v} \models \Psi_{\text{layout}}(\text{screen}, \mathbf{c}, \mathbf{s})$

Layout Solving

Goal

Compute absolute position of all the views

```
A.left = ?      B.left = ?  
A.right = ?     B.right = ?
```



$$B.left = A.right + 40$$

$$A.left = screen.left + 20$$

$$screen.left = 0 \wedge screen.right = 240$$

$$A.right - A.left = 80$$

$$B.right - B.left = 80$$

$$v \models \Psi_{\text{layout}}(\text{screen}, c, s)$$

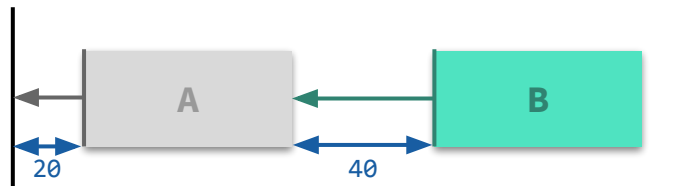
vs

Layout Synthesis

Goal

Synthesize position and size constraints

```
A.left = 0      B.left = 120  
A.right = 80    B.right = 200
```



?

?

$$screen.left = 0 \wedge screen.right = 240$$

?

?

$$c \wedge s \models \Psi_{\text{syn}}(\text{screen}, v)$$

Layout Solving

vs

Layout Synthesis

Approach

1. Encode the synthesis program as a logical formula $\psi_{\text{syn}}(\text{screen}, v)$
2. Find a satisfying assignment to $c \wedge s \models \psi_{\text{syn}}(\text{screen}, v)$

$$v \models \psi_{\text{layout}}(\text{screen}, c, s)$$

$$c \wedge s \models \psi_{\text{syn}}(\text{screen}, v)$$

Layout Synthesis

$$\Psi_{\text{syn}}(\text{screen}, \mathbf{v}) = \underbrace{\varphi_{\text{position}}(\text{screen}, \mathbf{v})}_{\text{Input Specification}} \wedge \underbrace{\varphi_{\text{constraints}}(\mathbf{v})}_{\text{Constraints Encoding}} \wedge \underbrace{\varphi_{\text{valid}}(\mathbf{v}) \wedge \varphi_{\text{acyclic}}(\mathbf{v})}_{\text{Ensure Constraints are Valid}}$$

Layout Synthesis

$$\Psi_{\text{syn}}(\text{screen}, \mathbf{v}) = \underbrace{\varphi_{\text{position}}(\text{screen}, \mathbf{v})}_{\text{Input Specification}} \wedge \underbrace{\varphi_{\text{constraints}}(\mathbf{v})}_{\text{Constraints Encoding}} \wedge \underbrace{\varphi_{\text{valid}}(\mathbf{v}) \wedge \varphi_{\text{acyclic}}(\mathbf{v})}_{\text{Ensure Constraints are Valid}}$$

$$\varphi_{\text{position}} \stackrel{\text{def}}{=} \begin{aligned} &\text{screen.left} = 0 \quad \wedge \\ &\text{screen.right} = 240 \quad \wedge \\ &\quad \text{A.left} = 0 \quad \wedge \\ &\quad \text{A.right} = 80 \quad \wedge \\ &\quad \text{B.left} = 120 \quad \wedge \\ &\quad \text{B.right} = 200 \end{aligned}$$

Layout Synthesis

$$\Psi_{\text{syn}}(\text{screen}, \mathbf{v}) = \underbrace{\varphi_{\text{position}}(\text{screen}, \mathbf{v})}_{\text{Input Specification}} \wedge \underbrace{\varphi_{\text{constraints}}(\mathbf{v})}_{\text{Constraints Encoding}} \wedge \underbrace{\varphi_{\text{valid}}(\mathbf{v}) \wedge \varphi_{\text{acyclic}}(\mathbf{v})}_{\text{Ensure Constraints are Valid}}$$

Layout Synthesis

What are the possible constraints for view B?

$$C(B, v, \text{screen}) = \{c_1^B, c_2^B, c_3^B, \dots, c_n^B\}$$

Layout Synthesis

What are the possible constraints for view B?

$$C(B, v, \text{screen}) = \{c_1^B, c_2^B, c_3^B, \dots, c_n^B\}$$



$$B.\text{left} = A.\text{right} + m_L \quad (c_1)$$

Layout Synthesis

What are the possible constraints for view B?

$$C(B, v, \text{screen}) = \{c_1^B, c_2^B, c_3^B, \dots, c_n^B\}$$



$$B.\text{left} = A.\text{right} + m_L \quad (c_1)$$



$$B.\text{left} = \text{screen}.\text{right} + m_L \quad (c_2)$$

Layout Synthesis

What are the possible constraints for view B?

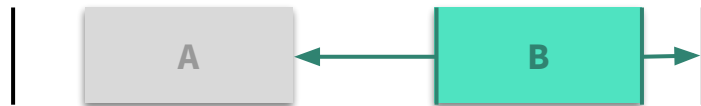
$$C(B, v, \text{screen}) = \{c_1^B, c_2^B, c_3^B, \dots, c_n^B\}$$



$$B.\text{left} = A.\text{right} + m_L \quad (c_1)$$



$$B.\text{left} = \text{screen}.\text{right} + m_L \quad (c_2)$$



$$(1-b) * B.\text{left} + b * B.\text{right} = (1-b) * (A.\text{right} + m_L) + b * (\text{screen}.\text{right} - m_R) \quad (c_3)$$

Layout Synthesis

What are the possible constraints for view B?

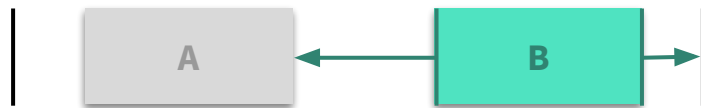
$$C(B, v, \text{screen}) = \{c_1^B, c_2^B, c_3^B, \dots, c_n^B\} \quad \leftarrow O(|v|^2)$$



$$B.\text{left} = A.\text{right} + m_L \quad (c_1)$$



$$B.\text{left} = \text{screen}.\text{right} + m_L \quad (c_2)$$



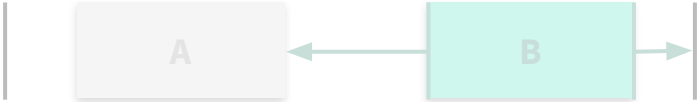
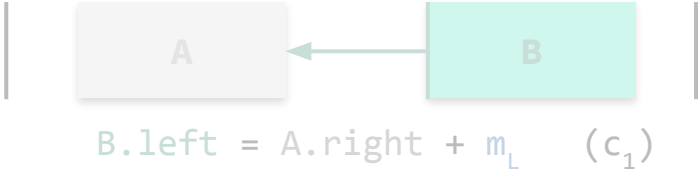
$$(1-b) * B.\text{left} + b * B.\text{right} = (1-b) * (A.\text{right} + m_L) + b * (\text{screen}.\text{right} - m_R) \quad (c_3)$$

Layout Synthesis

What are the possible constraints for view B?

$$C(B, v, \text{screen}) = \{c_1^B, c_2^B, c_3^B, \dots, c_n^B\} \leftarrow O(|v|^2)$$

Select exactly one constraint for each view



Layout Synthesis

What are the possible constraints for view B?

$$C(B, v, \text{screen}) = \{c_1^B, c_2^B, c_3^B, \dots, c_n^B\} \quad \leftarrow O(|v|^2)$$

Select exactly one constraint for each view

Boolean variables
denoting whether
constraint was selected

$$\left\{ \begin{array}{ll} g_1 \Rightarrow (B.\text{left} = A.\text{right} + m_L) & (c_1) \\ g_2 \Rightarrow (B.\text{left} = A.\text{left} + m_L) & (c_2) \\ & \dots \\ g_n \Rightarrow ((1-b)*B.\text{left} + b*B.\text{right} = \dots) & (c_n) \end{array} \right.$$

Layout Synthesis

What are the possible constraints for view B?

$$C(B, v, \text{screen}) = \{c_1^B, c_2^B, c_3^B, \dots, c_n^B\} \quad \leftarrow O(|v|^2)$$

$$\varphi_{\text{constraints}}(\text{screen}, v) \stackrel{\text{def}}{=} \underbrace{\left(\bigwedge_{k=0}^{C(B, v, \text{screen})} g_k \Rightarrow \llbracket c_k \rrbracket \right)}_{\text{View constraints}} \wedge \underbrace{g_0 + \dots + g_{|C(B, v, \text{screen})|}}_{\text{Select exactly one constraint for each view}} = 1$$

**Boolean variables
denoting whether
constraint was selected**

$$\left\{ \begin{array}{ll} g_1 \Rightarrow (B.\text{left} = A.\text{right} + m_L) & (c_1) \\ g_2 \Rightarrow (B.\text{left} = A.\text{left} + m_L) & (c_2) \\ & \dots \\ g_n \Rightarrow ((1-b)*B.\text{left} + b*B.\text{right} = \dots) & (c_n) \end{array} \right.$$

Layout Synthesis

What are the possible constraints for view B?

$$C(B, v, \text{screen}) = \{c_1^B, c_2^B, c_3^B, \dots, c_n^B\} \quad \leftarrow O(|v|^2)$$

$$\varphi_{\text{constraints}}(\text{screen}, v) \stackrel{\text{def}}{=} \bigwedge_{i=0}^{|v|} \left(\underbrace{\bigwedge_{k=0}^{C(v^i, v, \text{screen})} g_k^i \Rightarrow \llbracket c_k^i \rrbracket}_{\text{View constraints}} \right) \wedge \underbrace{g_0^i + \dots + g_{|C(v^i, v, \text{screen})|}^i = 1}_{\text{Select exactly one constraint for each view}} = 1$$

Boolean variables denoting whether constraint was selected

$$\left\{ \begin{array}{l} g_1 \Rightarrow (B.\text{left} = A.\text{right} + m_L) \quad (c_1) \\ g_2 \Rightarrow (B.\text{left} = A.\text{left} + m_L) \quad (c_2) \\ \dots \\ g_n \Rightarrow ((1-b) * B.\text{left} + b * B.\text{right} = \dots) \quad (c_n) \end{array} \right.$$

Layout Synthesis

$$\Psi_{\text{syn}}(\text{screen}, \mathbf{v}) = \underbrace{\varphi_{\text{position}}(\text{screen}, \mathbf{v})}_{\text{Input Specification}} \wedge \underbrace{\varphi_{\text{constraints}}(\mathbf{v})}_{\text{Constraints Encoding}} \wedge \underbrace{\varphi_{\text{valid}}(\mathbf{v}) \wedge \varphi_{\text{acyclic}}(\mathbf{v})}_{\text{Ensure Constraints are Valid}}$$

Layout Synthesis

$$\Psi_{\text{syn}}(\text{screen}, \mathbf{v}) = \underbrace{\varphi_{\text{position}}(\text{screen}, \mathbf{v})}_{\text{Input Specification}} \wedge \underbrace{\varphi_{\text{constraints}}(\mathbf{v})}_{\text{Constraints Encoding}} \wedge \underbrace{\varphi_{\text{valid}}(\mathbf{v}) \wedge \varphi_{\text{acyclic}}(\mathbf{v})}_{\text{Ensure Constraints are Valid}}$$

$$\varphi_{\text{valid}}(\mathbf{v}) \stackrel{\text{def}}{=} \begin{aligned} & (m_L \geq 0) \wedge (m_R \geq 0) \wedge \\ & (0 \leq b \leq 1) \wedge \\ & (0 \leq \alpha < 360) \wedge (r \geq 0) \end{aligned}$$



Layout Synthesis

$$\Psi_{\text{syn}}(\text{screen}, \mathbf{v}) = \underbrace{\varphi_{\text{position}}(\text{screen}, \mathbf{v})}_{\text{Input Specification}} \wedge \underbrace{\varphi_{\text{constraints}}(\mathbf{v})}_{\text{Constraints Encoding}} \wedge \underbrace{\varphi_{\text{valid}}(\mathbf{v}) \wedge \varphi_{\text{acyclic}}(\mathbf{v})}_{\text{Ensure Constraints are Valid}}$$

$$\Psi_{\text{syn}}(\text{screen}, \mathbf{v}) \rightarrow \text{Solver} \rightarrow \mathbf{c} \wedge \mathbf{s}$$

$$\mathbf{c} \wedge \mathbf{s} \models \Psi_{\text{syn}}(\text{screen}, \mathbf{v})$$

Layout Synthesis

$$\Psi_{\text{syn}}(\text{screen}, \mathbf{v}) = \underbrace{\varphi_{\text{position}}(\text{screen}, \mathbf{v})}_{\text{Input Specification}} \wedge \underbrace{\varphi_{\text{constraints}}(\mathbf{v})}_{\text{Constraints Encoding}} \wedge \underbrace{\varphi_{\text{valid}}(\mathbf{v}) \wedge \varphi_{\text{acyclic}}(\mathbf{v})}_{\text{Ensure Constraints are Valid}}$$

$$\Psi_{\text{syn}}(\text{screen}, \mathbf{v}) \rightarrow \text{Solver} \rightarrow \mathbf{c} \wedge \mathbf{s}$$

$$\mathbf{c} \wedge \mathbf{s} \models \Psi_{\text{syn}}(\text{screen}, \mathbf{v})$$

Are We Done?

Layout Synthesis

$$\Psi_{\text{syn}}(\text{screen}, \mathbf{v}) = \underbrace{\varphi_{\text{position}}(\text{screen}, \mathbf{v})}_{\text{Input Specification}} \wedge \underbrace{\varphi_{\text{constraints}}(\mathbf{v})}_{\text{Constraints Encoding}} \wedge \underbrace{\varphi_{\text{valid}}(\mathbf{v}) \wedge \varphi_{\text{acyclic}}(\mathbf{v})}_{\text{Ensure Constraints are Valid}}$$

$$\Psi_{\text{syn}}(\text{screen}, \mathbf{v}) \rightarrow \text{Solver} \rightarrow \mathbf{c} \wedge \mathbf{s}$$

$$\mathbf{c} \wedge \mathbf{s} \models \Psi_{\text{syn}}(\text{screen}, \mathbf{v})$$

Are We Done? No

Layout Synthesis

Considers only
Single Device

$$\Psi_{\text{syn}}(\text{screen}, \mathbf{v}) = \underbrace{\varphi_{\text{position}}(\text{screen}, \mathbf{v})}_{\text{Input Specification}} \wedge \underbrace{\varphi_{\text{constraints}}(\mathbf{v})}_{\text{Constraints Encoding}} \wedge \underbrace{\varphi_{\text{valid}}(\mathbf{v}) \wedge \varphi_{\text{acyclic}}(\mathbf{v})}_{\text{Ensure Constraints are Valid}}$$

max **4** views
Scalability

13%
Generalization

Are We Done? **No**

Layout Synthesis

Considers only
Single Device

$$\Psi_{\text{syn}}(\text{screen}, \mathbf{v}) = \underbrace{\varphi_{\text{position}}(\text{screen}, \mathbf{v})}_{\text{Input Specification}} \wedge \underbrace{\varphi_{\text{constraints}}(\mathbf{v})}_{\text{Constraints Encoding}} \wedge \underbrace{\varphi_{\text{valid}}(\mathbf{v}) \wedge \varphi_{\text{acyclic}}(\mathbf{v})}_{\text{Ensure Constraints are Valid}}$$



GitHub

Probabilistic Model



User Feedback



Generalize to
Multiple Devices

Are We Done? **No**

Natural Layouts

$$\Psi_{\text{syn}}(\text{screen}, \mathbf{v}) = \underbrace{\varphi_{\text{position}}(\text{screen}, \mathbf{v}) \wedge \varphi_{\text{constraints}}(\mathbf{v}) \wedge \varphi_{\text{valid}}(\mathbf{v}) \wedge \varphi_{\text{acyclic}}(\mathbf{v})}_{\left. \begin{array}{l} \max \sum_{i=0}^{|\mathbf{c}|} \log P(c_i \mid \text{screen}, \mathbf{v}) \end{array} \right\} \text{Probability of each selected constraint} \\ \text{according to learned probabilistic model}}$$

$$\Psi_{\text{syn}}(\text{screen}, \mathbf{v}) \rightarrow \text{Solver} \rightarrow \mathbf{c} \wedge \mathbf{s}$$

the most likely
synthesize ~~any~~ layout
that satisfies the specification

Natural Layouts

$$\Psi_{\text{syn}}(\text{screen}, \mathbf{v}) = \underbrace{\varphi_{\text{position}}(\text{screen}, \mathbf{v}) \wedge \varphi_{\text{constraints}}(\mathbf{v}) \wedge \varphi_{\text{valid}}(\mathbf{v}) \wedge \varphi_{\text{acyclic}}(\mathbf{v})}_{\left. \begin{array}{l} \max \sum_{i=0}^{|\mathbf{c}|} \log P(c_i \mid \text{screen}, \mathbf{v}) \end{array} \right\} \text{Probability of each selected constraint} \\ \text{according to learned probabilistic model}}$$

max **4** views → **12** views

Scalability

13% → **75%**

Generalization

Probabilistic Model

Learn a probabilistic model that predicts likelihood that a constraint is used

$$P(c \mid \text{screen}, \mathbf{v}) \rightarrow \mathbb{R}^{<0, 1>}$$

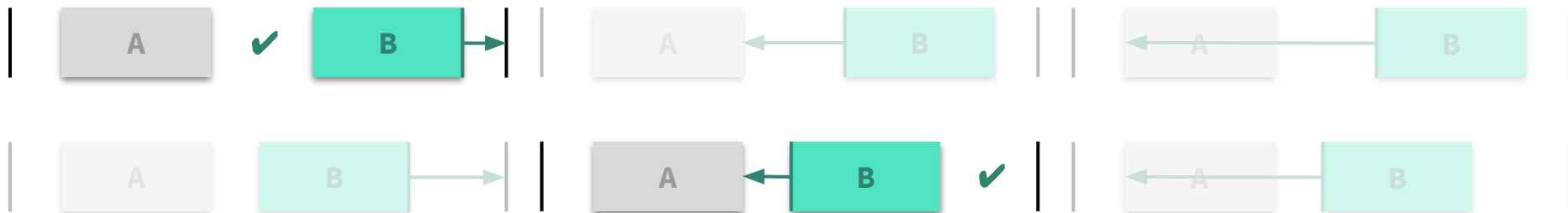


Which constraint is most likely?

Probabilistic Model

Learn a probabilistic model that predicts likelihood that a constraint is used

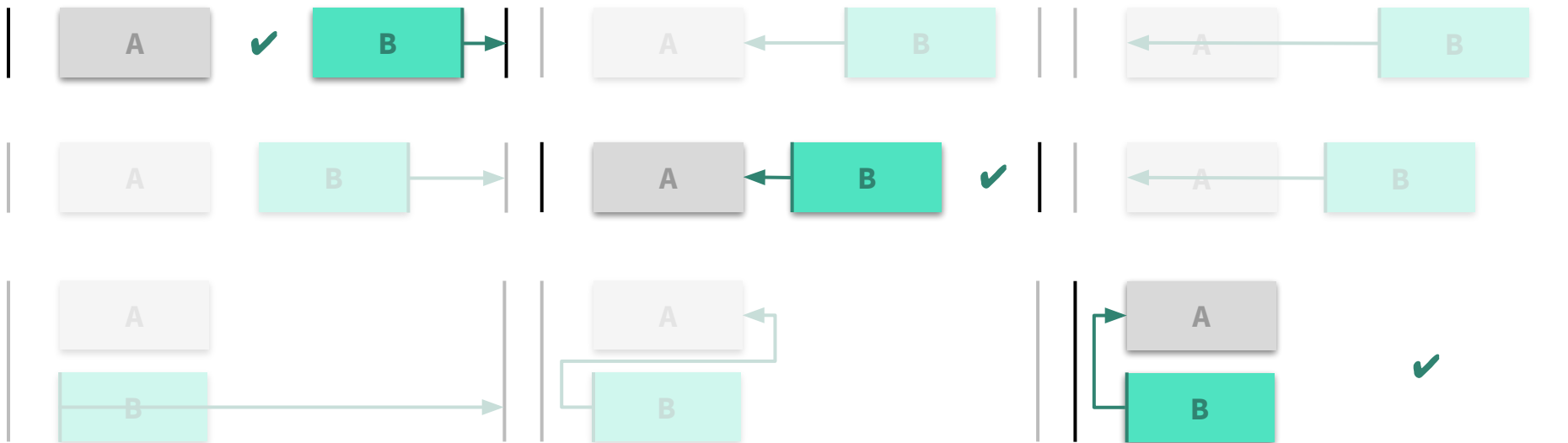
$$P(c \mid \text{screen}, \mathbf{v}) \rightarrow \mathbb{R}^{<0, 1>}$$



Probabilistic Model

Learn a probabilistic model that predicts likelihood that a constraint is used

$$P(c \mid \text{screen}, \mathbf{v}) \rightarrow \mathbb{R}^{<0, 1>}$$



Probabilistic Model

$$P(c \mid \text{screen}, \mathbf{v}) = \frac{1}{Z(\text{screen}, \mathbf{v})} \prod P_f (c \mid f_k(c, \text{screen}, \mathbf{v}))^{w_k}$$

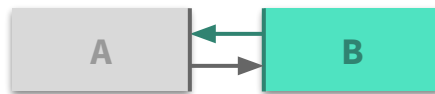
f_b Bias

b

f_d Distance



f_t Constraint Type



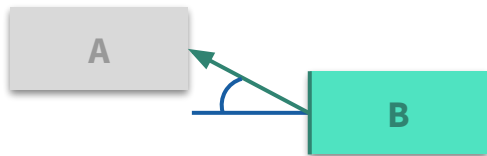
f_i Intersection



f_m Margins

$\langle m_L, m_R \rangle$

f_o Orientation



f_s Size



f_c Complexity

$b == \emptyset$
 $m_L == \emptyset, m_R == \emptyset$

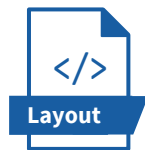
All Trained using Maximum Likelihood Estimation

Generalize to Multiple Devices

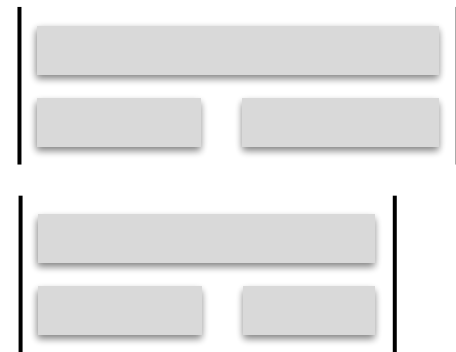
1. Synthesize Layout Using Input Specification



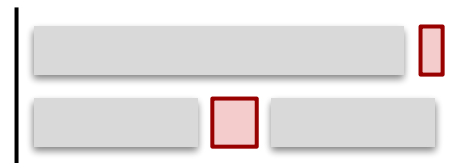
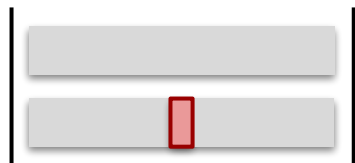
Synthesis



2. Render on Multiple Devices



3. Check that Synthesized Layout Generalizes



Generalize to Multiple Devices

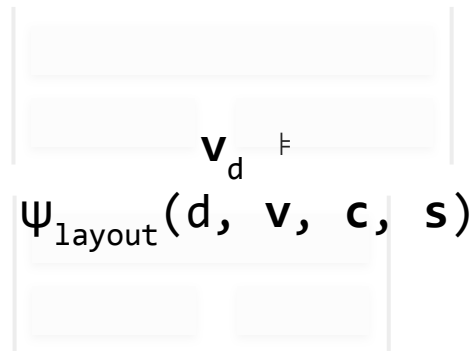
1. Synthesize Layout Using Input Specification



$$\rightarrow \Psi_{\text{syn}}(\text{screen}, \mathbf{v}) \quad \mathbf{c} \wedge \mathbf{s} \models$$



2. Render on Multiple Devices



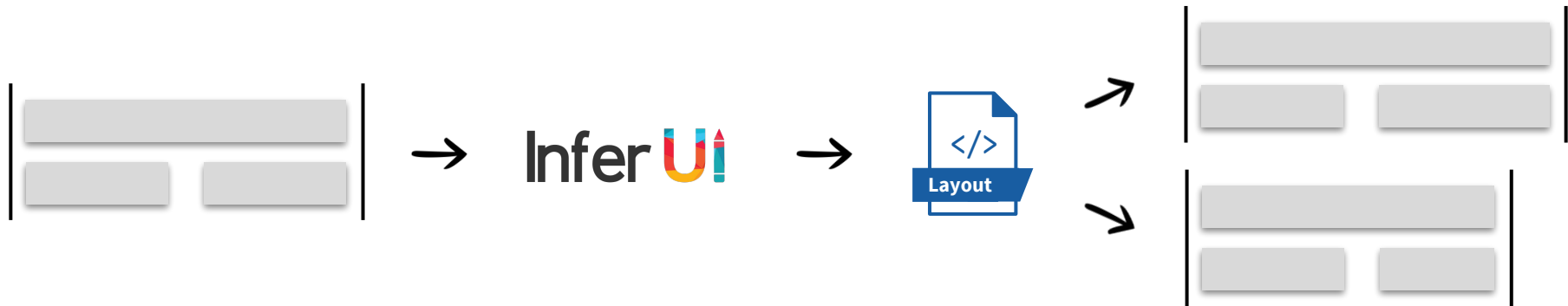
3. Check that Synthesized Layout Generalizes

$$\begin{aligned} & \varphi_{\text{preserve_aspect_ratio}}(\mathbf{v}, \mathbf{v}_d) \wedge \varphi_{\text{inside_screen}}(\mathbf{d}, \mathbf{v}_d) \wedge \\ & \varphi_{\text{pixel_perfect}}(\mathbf{v}_d) \wedge \varphi_{\text{preserve_order}}(\mathbf{v}, \mathbf{v}_d) \wedge \\ & \varphi_{\text{preserve_centering}}(\mathbf{v}, \mathbf{v}_d) \wedge \varphi_{\text{preserve_margins}}(\mathbf{v}, \mathbf{v}_d) \end{aligned}$$

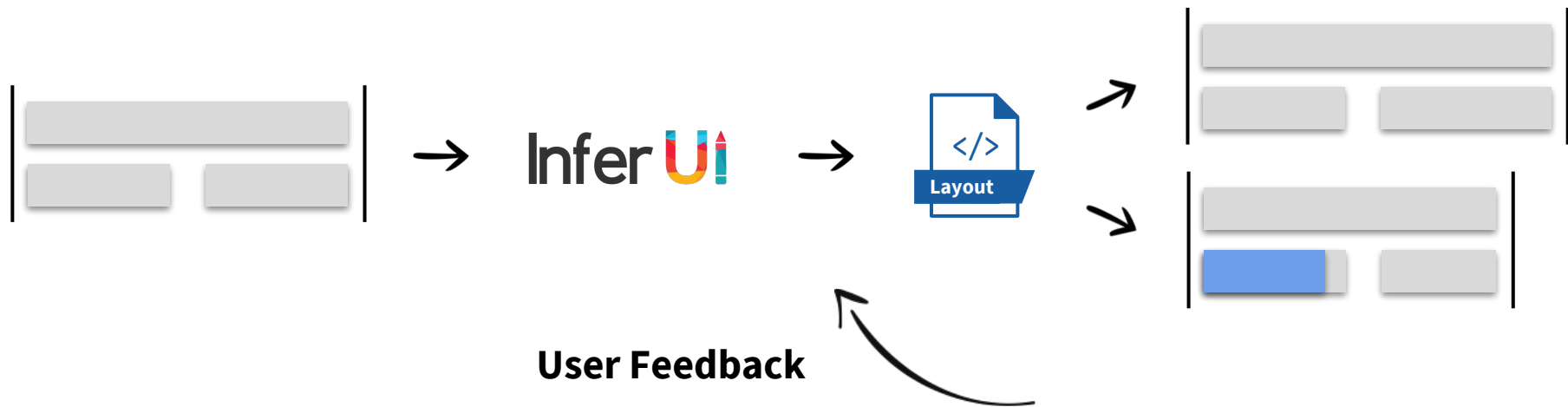
} Set of Robustness Properties

All Steps Encoded as a Single Formula!

User Feedback



User Feedback



$$\Psi_{\text{user_feedback}} \stackrel{\text{def}}{=} B_k.\text{left} = 120 \wedge B_k.\text{right} = 200$$

Evaluation

Infer U!

Top 500



Top 500

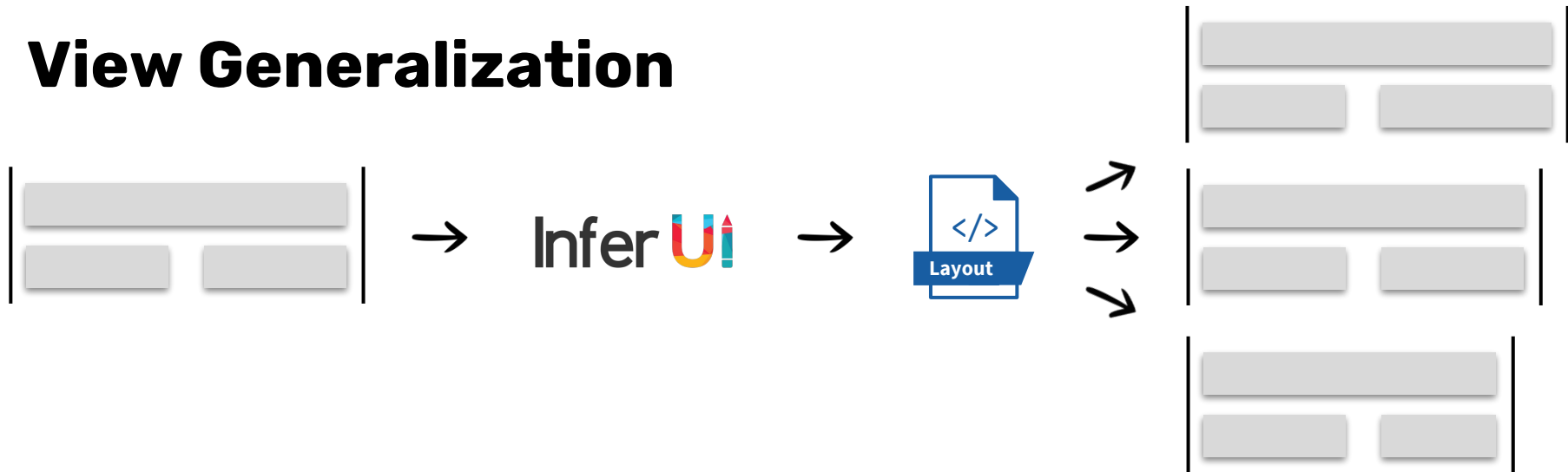
GitHub

Evaluation

Synthesis Success Ratio / Runtime

	[2, 4)	[4, 8)	[8, 12)	[12, 16)	
Single Device	100%	100%	100%	100%	} Number of Views
	37 ms	59 ms	129 ms	519 ms	} Success Ratio
					} Average Synthesis Time
Multi Device	99%	93%	73%	56%	
	44 ms	95 ms	314 ms	3 s	

View Generalization



Percentage of Views That Correctly Generalize

13%



75%



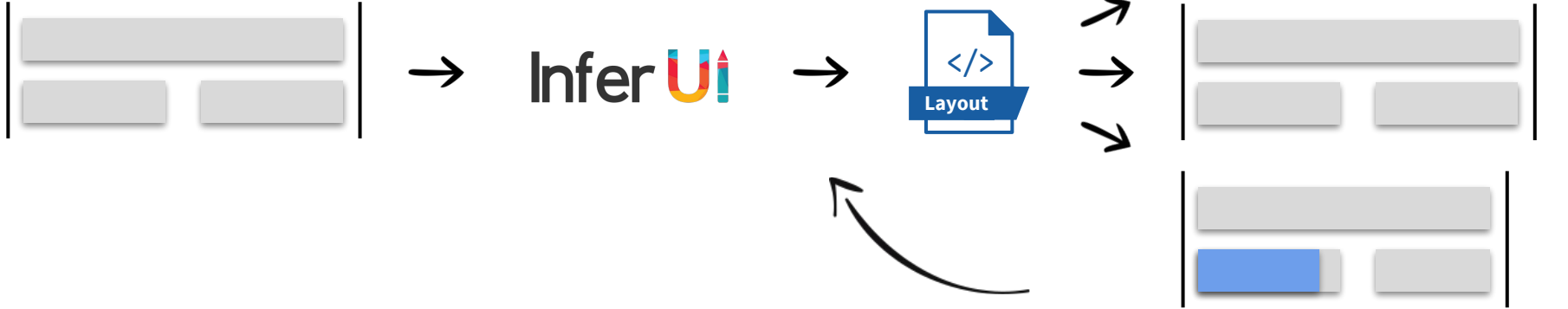
92%

$\Psi_{\text{single_syn}}(\text{screen}, \mathbf{v})$

+ Probabilistic
Model

+ Robustness
Properties

User Feedback



Number of User Feedbacks Required

63%

no feedback

25%

1 feedback

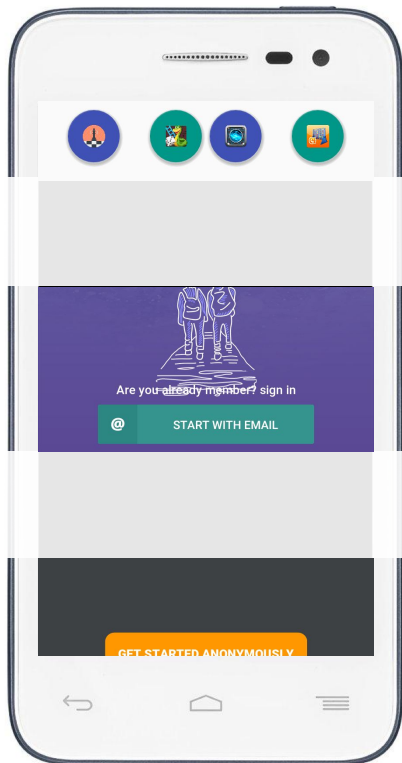
8%

2 feedbacks

4%

3+ feedbacks

Layout Errors



24

(5%)

$\neg\varphi_{\text{preserve_margins}}$

4

(0.8%)

$\neg\varphi_{\text{preserve_aspect_ratio}}$

19

(4%)

$\neg\varphi_{\text{preserve_order}}$

41

(8.5%)

$\neg\varphi_{\text{pixel_perfect}}$

21

(4%)

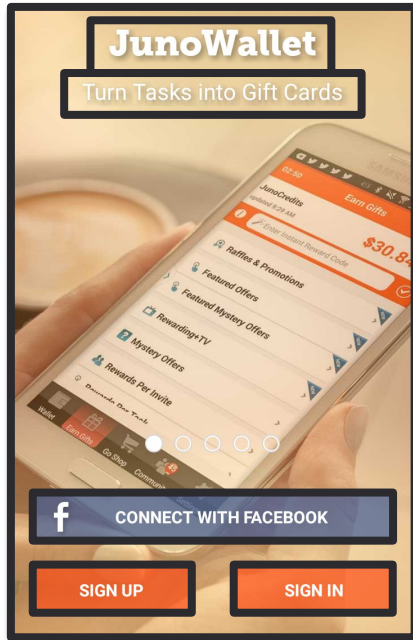
$\neg\varphi_{\text{inside_screen}}$

16

(3.3%)

$\neg\varphi_{\text{preserve_centering}}$

Infer U

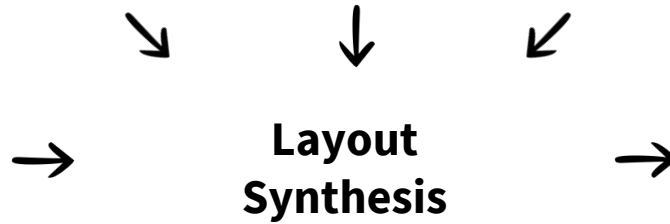


Design Specification

Layout Formalization

Robustness Properties

User Feedback



List of Devices



Probabilistic Model

GitHub

