# S244-Group Photo 

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## Background

Problem idea by kctung
Preparation by VCLH and __declspec

## Problem Restatement

Arrange 2 N students（each with distinct height from 1 to 2 N ）into 2 rows of N students such that：
－$F$ students will be blocked when facing front： $\mathrm{C}_{\mathrm{i}}(=0 / 1)$ in the i －th column －$\Sigma C_{i}=F$
－$L$ students will be blocked when facing left：either
－$R_{1}$ blocked in the front row，$R_{2}$ in the back row，with $L=R_{1}+R_{2}$ ；or
－$R_{1}=R_{2}=-1$ ，i．e．you get to decide how many be blocked in each row
＂If there does not exist a consistent arrangement of heights，output－1．＂

## Sample 1



First photo with everyone facing front


Second photo with everyone facing left


## Statistics

|  | $N+H+B+S+G=$ | $T$ |
| :--- | ---: | ---: | ---: |
| D．N．A． | $20+9+10+2+0=$ | 41 |
| 0 points | $4+1+3+1+0=$ | 9 |
| 5 points | $2+2+1+0+0=$ | 5 |
| 8 points | $1+1+2+0+\theta=$ | 4 |
| 12 points | $0+0+3+1+\theta=$ | 4 |
| 13 points | $0+1+1+0+0=$ | 2 |
| 16 points | $0+0+1+1+0=$ | 2 |
| 20 points | $0+1+0+3+1=$ | 5 |
| 28 points | $0+0+0+6+1=$ | 7 |
| 37 points | $0+0+0+0+6=$ | 6 |
| Total | $27+15+21+14+8=$ | 85 |

## Subtasks

## Points Constraints

$15 \quad N=2$
$2 \quad 7 \quad N \leq 5$
For all cases：
$2 \leq N \leq 100$
$38 \quad R_{1}=R_{2}=-1$
$L$ is even
$0 \leq F \leq N$
$0 \leq L \leq 2(N-1)$
$0 \leq C_{1}, C_{2}, \ldots, C_{N} \leq 1$
$C_{1}+C_{2}+\cdots+C_{N}=F$
Either $R_{1}=R_{2}=-1$ ，or $0 \leq R_{1}, R_{2} \leq N-1$ and $R_{1}+R_{2}=L$ ．

4
526
$0 \leq R_{1} \leq R_{2} \leq N-2$
$7 \quad 37 \quad$ No additional constraints

## Subtask 1 （5 pts）：N＝ 2

Sanity check（？）（very annoying in this task）
Exhaust all scenarios by hand
－With $R_{1}$ and $R_{2}$ specified：

$$
\begin{array}{ll}
2^{N} \times N^{2} & =16 \\
2^{N} \times(2 N-1) & =12
\end{array}
$$

－$R_{1}=R_{2}=-1$ ：

Score： 5
Time Complexity：O（1）

## Subtask 1 （5 pts）：N＝ 2

## Observations：

－$F$ is basically redundant，since $F=\Sigma C_{j}$
－$L$ is also redundant when $R_{1}$ and $R_{2}$ are given
－When $R_{1}=R_{2}=-1$ ，they can easily be determined by $L$ when $N=2$ ：

$$
\begin{array}{llll}
\circ & L=0 & \Leftrightarrow & R_{1}=R_{2}=0 \\
\circ & L=2 & \Leftrightarrow & R_{1}=R_{2}=1 \\
\circ & L=1 & \Leftrightarrow & \left(R_{1}, R_{2}\right)=(0,1) \text { or }(1,0) \text { : Just try both }
\end{array}
$$

## Subtask 1 （5 pts）：N＝ 2

Denote the height of the student of row－i－column－j as h［i］［j］．
Observations：
－Since each column has only two person，
－ $\mathrm{C}_{\mathrm{j}}$＇s are basically inequality signs：
$\begin{array}{llllll}\circ & C_{j}=0 & \Leftrightarrow & h[1][j]<h[2][j] & \Leftrightarrow & \text { Not blocked } \\ \circ & C_{1}=1 & \Leftrightarrow & h[1][j]>h[2][j] & \Leftrightarrow & \text { Blocked }\end{array}$
$\circ C_{j}=1 \Leftrightarrow h[1][j]>h[2][j] \Leftrightarrow$ Blocked

## Subtask 1 （5 pts）：N＝ 2

Denote the height of the student of row－i－column－j as h［i］［j］．
Observations：
－ $\mathrm{C}_{\mathrm{j}}$＇s are basically inequality signs．
－$R_{i}^{\prime}$＇s（if given）are also inequality signs when $\mathrm{N}=2$ ．
$\Rightarrow$ We can fill in the $2 \times 2$ grid following the inequality signs

## Subtask 1 （5 pts）：N＝ 2

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Observations：
－ $\mathrm{C}_{\mathrm{j}}$＇s are basically inequality signs．
－$R_{i}$＇s（if given）are also inequality signs when $N=2$ ．
$\Rightarrow$ We can fill in the $2 \times 2$ grid following the inequality signs

|  | 2 1 <br> 1 0 <br> 1 1 | $>$ | 1 |
| :--- | :--- | :--- | :--- | :--- |
|  | 1 |  |  |$|$|  |  |
| :--- | :--- |
|  |  |

## Subtask 1 （5 pts）：N＝ 2

Question：Out of the $28(16+12)$ scenarios，which of them are IMPOSSIBLE to have consistent height arrangements？
Answer：
－Always possible when $R_{1}=R_{2}=-1$
－ 2 of the 16 scenarios with specified R＇s are impossible：

Sample 3，and its symmetrical equivalent

## Sample 3 - N = 2

## 211 <br> 01 <br> 10


$\begin{array}{lll}2 & 1 & 1 \\ 1 & 0 & \\ 0 & 1 & \end{array}$


## Sample 3 －N＝ 2

211
01
10

$\Rightarrow$ The inequalities form a LOOP

Bear this in mind ．．．will revisit this later

## Subtask 2 （ 7 pts）： $\mathrm{N} \leq 5$

－Exhaust all（2N）！height arrangements
－next＿permutation
－Check whether each arrangement meets all given constraints

Score： 12
Time Complexity：O（（2N）！× N）

## Subtask 3 （ 8 pts ）：$R_{1}=R_{2}=-1$ ，and $L$ is even

－$R_{1}=R_{2}=-1 \Rightarrow$ You get to decide how many be blocked in each row
－$L$ is even $\quad \Rightarrow$ An intuitive thought：why not just divide it by 2 ？

Recall our observations：
－ $\mathrm{C}_{\mathrm{j}}$＇s are basically inequality signs．
－ $\mathrm{R}_{\mathrm{i}}$＇s（if given）are also inequality signs when $\mathrm{N}=2$ ．
$\Rightarrow$ For general N ，what can we tell from R ？

## Problem Simplification：One－Row Version

Let＇s just focus on one row for now．
－R denotes the number of students blocked in the row．
－Who will never be blocked？
－（1）The first／leftmost student
－（2）The tallest student in the row
－Who will always be blocked？
－（3）The students to the right of the tallest student

From（1），we have $0 \leq R \leq N-1$ ．

## Problem Simplification：One－Row Version

For（2）and（3），consider the position（column）of the tallest student．
－If the tallest student is in position H ，
－Then $(\mathrm{N}-\mathrm{H})$ students to his／her right will be blocked．
Therefore，we have

$$
\mathrm{R} \geq \mathrm{N}-\mathrm{H}, \quad \mathrm{H} \geq \mathrm{N}-\mathrm{R}
$$

－If $\mathrm{H}=\mathrm{N}-\mathrm{R}$ ，then no one to the left of H cannot be blocked．
－If $\mathrm{H}>\mathrm{N}-\mathrm{R}$ ，then someone to the left of H needs to be blocked．

## Problem Simplification：One－Row Version

An easy way to construct one row with a given R ：
－Denote the position of the tallest person in the row as H ．
－Set H＝N－R
－Position 1 －（H－1）：Heights in ascending order（so no one is blocked）
－Position H： Largest height
－Position $(\mathrm{H}+1)-\mathrm{N}$ ：Height order does not matter


## Subtask 3 （ 8 pts ）：$R_{1}=R_{2}=-1$ ，and $L$ is even

Back to original two－row version：
－Set $R_{1}=R_{2}=L / 2$ ，and $H_{1}=H_{2}=N-R_{i}$
－What about the interaction between the two rows？
－ $\mathrm{C}_{\mathrm{j}}$＇s are basically inequality signs．


## Subtask 3 （8 pts）：$R_{1}=R_{2}=-1$ ，and $L$ is even

Back to original two－row version：
－One more note：avoid creating loops
－Easiest way is to fill the ？＇s with all＜＇s（or all＞＇s）
－Then assign the heights column－by－column


Score： 8 （Cumulative：20）
Time Complexity：O（N）

## Subtask 4 （ 9 pts ）： $\mathrm{R}_{1}=\mathrm{R}_{2}=-1$

－$L$ is even：Set $R_{1}$ and $R_{2}$ to be the same：Handled in Subtask 3
－$L$ is odd：$R_{1}$ and $R_{2}$ must be different

We can first assume

$$
R_{1}=(L-1) / 2, \quad R_{2}=(L+1) / 2
$$

Score： 17 （Cumulative：29）
Time Complexity： $\mathrm{O}(\mathrm{N})$

Subtask 4 （9 pts）： $\mathrm{R}_{1}=\mathrm{R}_{2}=-1$

$$
\mathrm{R}_{1}=\mathrm{R}_{2}-1, \quad \mathrm{H}_{1}=\mathrm{H}_{2}+1
$$

Under what conditions will the constraints be inconsistent？


Subtask 4 （9 pts）： $\mathrm{R}_{1}=\mathrm{R}_{2}=-1$

$$
\mathrm{R}_{1}=\mathrm{R}_{2}-1, \quad \mathrm{H}_{1}=\mathrm{H}_{2}+1
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Subtask 4 （9 pts）： $\mathrm{R}_{1}=\mathrm{R}_{2}=-1$

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\mathrm{R}_{1}=\mathrm{R}_{2}-1, \quad \mathrm{H}_{1}=\mathrm{H}_{2}+1
$$

Under what conditions will the constraints be inconsistent？


## Subtask 5 （8 pts）： $0 \leq R_{1} \leq R_{2} \leq N-2$ ，and all $C_{j}=0$

－ $0 \leq R_{1} \leq R_{2} \leq N-2$
Not really matters in this subtask；what matters is
－All $\mathrm{C}_{\mathrm{j}}=0 \Rightarrow$ Every student in row 1 is shorter than its row 2 counterpart
$\Rightarrow$ Simply make the whole row 1 shorter than whole row 2

Score： 8 （Cumulative：37）
Time Complexity： $\mathrm{O}(\mathrm{N})$

## Subtask 6 （26 pts）： $0 \leq R_{1} \leq R_{2} \leq N-2$

Denote the leftmost position the tallest person in row i can be at as $H_{i}^{\prime}=N-R_{i}$
－ $0 \leq R_{1} \leq R_{2} \leq N-2 \Rightarrow 2 \leq H_{2}{ }^{\prime} \leq H_{1}{ }^{\prime} \leq N$
－If $R_{1}=R_{2}$ ，just handle like in Subtask 3

－For the rest of this subtask，consider $R_{1}<R_{2}$

## Subtask 6＊（26 pts）： $0 \leq R_{1}<R_{2} \leq N-2$

Case 1： $\mathrm{C}\left[\mathrm{N}-\mathrm{R}_{2}\right]=0$


## Takeaway：Visualisation

Instead of treating 1－2N as actual heights，think of them as ranks：
－ 1 st to 2 N －th，ordinal numerals

That way when your thought is not limited to $1-2 \mathrm{~N}$ ，you can imagine
－e．g．the tallest student gets very tall，soared up by a lot
－e．g．the short students get very short

Even better to visualise them，e．g．by line graph
－Enjoy properties such as trends，peaks，troughs

## Subtask 6＊（26 pts）： $0 \leq R_{1}<R_{2} \leq N-2$

Case 1： $\mathrm{C}\left[\mathrm{N}-\mathrm{R}_{2}\right]=0$


## Subtask 6＊（26 pts）： $0 \leq R_{1}<R_{2} \leq N-2$

Case 2：$C\left[N-R_{2}\right]=1$ ．Let $\underline{x}$ be the smallest index $>\left(N-R_{2}\right)$ such that $C_{x}=0$ ． Case 2a： $\mathrm{X} \leq \mathrm{N}-\mathrm{R}_{1}$


## Subtask 6＊（26 pts）： $0 \leq R_{1}<R_{2} \leq N-2$

Case 2： $\mathrm{C}\left[\mathrm{N}-\mathrm{R}_{2}\right]=1 . \quad$ Let $\underline{\mathrm{X}}$ be the smallest index $>\left(\mathrm{N}-\mathrm{R}_{2}\right)$ such that $\mathrm{C}_{\mathrm{x}}=0$ ． Case 2a： $\mathrm{X} \leq \mathrm{N}-\mathrm{R}_{1}$


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## Subtask 6＊（26 pts）： $0 \leq R_{1}<R_{2} \leq N-2$

Case 2： $\mathrm{C}\left[\mathrm{N}-\mathrm{R}_{2}\right]=1 . \quad$ Let $\varnothing$ be the smallest index $>\left(N-R_{2}\right)$ such that $\mathrm{C}_{\mathrm{x}}=0$ ． Case 2b： $\mathrm{N}-\mathrm{R}_{1}<\mathrm{X} \leq \mathrm{N}$



## Subtask 6＊（26 pts）： $0 \leq R_{1}<R_{2} \leq N-2$

Case 2： $\mathrm{C}\left[\mathrm{N}-\mathrm{R}_{2}\right]=1$ ．Let $\mathbb{\chi}$ be the smallest index $>\left(\mathrm{N}-\mathrm{R}_{2}\right)$ such that $\mathrm{C}_{\mathrm{x}}=0$ ． Case 2b： $\mathrm{N}-\mathrm{R}_{1}<\mathrm{X} \leq \mathrm{N}$


## Subtask 6＊（26 pts）： $0 \leq R_{1}<R_{2} \leq N-2$

Case 2： $\mathrm{C}\left[\mathrm{N}-\mathrm{R}_{2}\right]=1 . \quad$ Let $\underline{\chi}$ be the smallest index $>\left(N-R_{2}\right)$ such that $\mathrm{C}_{\mathrm{x}}=0$ ． Case 2b： $\mathrm{N}-\mathrm{R}_{1}<\mathrm{X} \leq \mathrm{N}$


## Subtask 6＊（26 pts）： $0 \leq R_{1}<R_{2} \leq N-2$

Case 2： $\mathrm{C}\left[\mathrm{N}-\mathrm{R}_{2}\right]=1 . \quad$ Let $\mathbb{X}$ be the smallest index $>\left(\mathrm{N}-\mathrm{R}_{2}\right)$ such that $\mathrm{C}_{\mathrm{x}}=0$ ．
Case 2c：no such $\begin{aligned} & \text { exists }\end{aligned}$


## Subtask 6 （26 pts）： $0 \leq R_{1} \leq R_{2} \leq N-2$

Tip：Divide the grid into sections with recognisable patterns
－Write some helper functions
－Makes your code cleaner and easier to understand


Score： 34 （Cumulative：63）
－Score with dividing $L$ into halves when $R_{1}=R_{2}=-1: 42$
Time Complexity： $\mathrm{O}(\mathrm{N})$

## Subtask 7 （37 pts）：No additional constraints

Two unanswered questions remain：
1．What if $R_{1}>R_{2}$ ？
2．What if $\max \left(R_{1}, R_{2}\right)=N-1$ ？

## Full Solution

1．What if $R_{1}>R_{2}$ ？

Consider swapping the two rows of any arbitrary height arrangement．
－The content within each row remains unchanged
－$\Rightarrow R_{1}$ and $R_{2}$ gets swapped
－Within each column，blocked person becomes unblocked，and vice versa
$\circ \quad \Rightarrow C_{j}$ gets flipped $(0 \rightarrow 1,1 \rightarrow 0) \quad F \leftarrow N-F$

Use a boolean variable to indicate rows being swapped，so that you can adjust back during the output stage．

## Full Solution

2．What if $0 \leq R_{1}<R_{2}=N-1$ ？

## Recall our early insights mentioned in Subtask 3：

－Who will never be blocked？
－（1）The first／leftmost student
－（2）The tallest student in the row

When $\mathrm{R}=\mathrm{N}-1$ ，only one student is not blocked，and he／she must be both the leftmost and the tallest student．

## Full Solution

2．What if $0 \leq R_{1}<R_{2}=N-1$ ？

The fact that Subtask 6＊is ALWAYS possible relies on the ability for $\mathrm{H}_{2}$ to shift rightwards along its row，without changing the number of blocked students．

This is not true when $\mathrm{R}_{2}=\mathrm{N}-1$ ．

## Full Solution－Case（ $0 \leq \mathrm{R}_{1}<\mathrm{R}_{2}=\mathrm{N}-1$ ）

Case 1： $\mathrm{C}[1]=0$
Always possible：Similar to Subtask 6 Case 1.


## Full Solution－Case（ $0 \leq \mathrm{R}_{1}<\mathrm{R}_{2}=\mathrm{N}-1$ ）

Case 2：C［1］＝ 1
Notice that loops are beginning to form．．．


## Full Solution－Case（ $0 \leq \mathrm{R}_{1}<\mathrm{R}_{2}=\mathrm{N}-1$ ）

Case 2： $\mathrm{C}[1]=1$
Recall $H_{i}^{\prime}=N-R_{i}$ is the leftmost position the tallest person in row $i$ can be at． If $H_{1}=H_{1}$ ，then for all $1 \leq k \leq H_{1}$ we have：
－ $\mathrm{h}[1][\mathrm{k}]>\mathrm{h}[1][1] \quad$（ascending order for position $1-\mathrm{H}_{1}$ ）
－ $\mathrm{h}[1][1]>\mathrm{h}[2][1] \quad(\mathrm{C}[1]=1)$
－ $\mathrm{h}[2][1]>\mathrm{h}[2][\mathrm{k}] \quad$（tallest in row 2）


## Full Solution－Case（ $0 \leq \mathrm{R}_{1}<\mathrm{R}_{2}=\mathrm{N}-1$ ）

Case 2： $\mathrm{C}[1]=1$
Recall $H_{i}^{\prime}=N-R_{i}$ is the leftmost position the tallest person in row $i$ can be at． If $H_{1}=H_{1}$ ，then for all $1 \leq k \leq H_{1}$ we have：
－ $\mathrm{h}[1][\mathrm{k}]>\mathrm{h}[1][1] \quad$（ascending order for position $1-\mathrm{H}_{1}$ ）
－ $\mathrm{h}[1][1]>\mathrm{h}[2][1] \quad(\mathrm{C}[1]=1)$
－ $\mathrm{h}[2][1]>\mathrm{h}[2][\mathrm{k}] \quad$（tallest in row 2）
$\Rightarrow \mathrm{h}[1][\mathrm{k}]>\mathrm{h}[2][\mathrm{k}]$
$\Rightarrow C[k]=1$


## Full Solution－Case（ $0 \leq \mathrm{R}_{1}<\mathrm{R}_{2}=\mathrm{N}-1$ ）

Case 2：C［1］＝ 1
If there is some k in $\left[1, \mathrm{H}_{1}\right]$ such that $\mathrm{C}[\mathrm{k}]=0$ ，we need to break the loop for the process to continue．
－h［1］$[k]>h[1][1]$（ascending order for position $1 \quad \mathrm{H}_{4} t$
－ $\mathrm{h}[1][1]>\mathrm{h}[2][1] \quad(\mathrm{C}[1]=1)$
－ $\mathrm{h}[2][1]>\mathrm{h}[2][\mathrm{k}] \quad$（tallest in row 2）

How？


## Full Solution－Case（ $0 \leq \mathrm{R}_{1}<\mathrm{R}_{2}=\mathrm{N}-1$ ）

Case 2：C［1］＝ 1
If there is some k in $\left[1, \mathrm{H}_{1}\right]$ such that $\mathrm{C}[\mathrm{k}]=0$ ，we need to break the loop for the process to continue．
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－ $\mathrm{h}[2][1]>\mathrm{h}[2][\mathrm{k}] \quad$（tallest in row 2）

How？Shift $\mathrm{H}_{1}$ by 1


## Full Solution－Case（ $0 \leq \mathrm{R}_{1}<\mathrm{R}_{2}=\mathrm{N}-1$ ）

Case 2：C［1］＝ 1
If there is some k in $\left[1, \mathrm{H}_{1}\right]$ such that $\mathrm{C}[\mathrm{k}]=0$ ，we need to break the loop for the process to continue．
－h［1］［k］$h[1][1]$（ascending order for position $1 \quad \mathrm{H}_{1} t$
－ $\mathrm{h}[1][1]>\mathrm{h}[2][1] \quad(\mathrm{C}[1]=1)$
－ $\mathrm{h}[2][1]>\mathrm{h}[2][\mathrm{k}] \quad$（tallest in row 2）

How？Shift $\mathrm{H}_{1}$ by 1


## Full Solution－Case（ $0 \leq \mathrm{R}_{1}<\mathrm{R}_{2}=\mathrm{N}-1$ ）

Case 2：C［1］＝ 1
If there is some k in $\left[1, \mathrm{H}_{1}\right]$ such that $\mathrm{C}[\mathrm{k}]=0$ ，we need to break the loop for the process to continue．
－h［1］［k］$\rightarrow h[1][1]$（ascending order for position $1 \quad \mathrm{H}_{4} t$
－ $\mathrm{h}[1][1]>\mathrm{h}[2][1] \quad(\mathrm{C}[1]=1)$
－ $\mathrm{h}[2][1]>\mathrm{h}[2][\mathrm{k}] \quad$（tallest in row 2）

How？Shift $H_{1}$ by 1 Until．．．


## Full Solution－Case（ $0 \leq \mathrm{R}_{1}<\mathrm{R}_{2}=\mathrm{N}-1$ ）

Case 2：C［1］＝ 1
If there is some k in $\left[1, \mathrm{H}_{1}\right]$ such that $\mathrm{C}[\mathrm{k}]=0$ ，we need to break the loop for the process to continue．
－h［1］$[k]>h[1][1]$（ascending order for position $1 \quad \mathrm{H}_{1} t$
－ $\mathrm{h}[1][1]>\mathrm{h}[2][1] \quad(\mathrm{C}[1]=1)$
－ $\mathrm{h}[2][1]>\mathrm{h}[2][\mathrm{k}] \quad$（tallest in row 2）

How？Shift $H_{1}$ by 1
Until no place left for $\mathrm{H}_{1}$ to shift
$\Rightarrow$ Return IMPOSSIBLE


## Full Solution－Case（ $0 \leq \mathrm{R}_{1}<\mathrm{R}_{2}=\mathrm{N}-1$ ）

Case 2：C［1］＝ 1
To formally state out the criteria，
－There are（ $\mathrm{N}-\mathrm{R}_{1}$ ）unblocked students（including column 1）
－Each of their $\left(N-R_{1}\right)$ columns must not form an inequality loop with column 1
$\Rightarrow$ Necessary condition：

$$
\#\left(C_{j}=1\right) \geq N-R_{1}
$$



## Full Solution－Case（ $0 \leq \mathrm{R}_{1}<\mathrm{R}_{2}=\mathrm{N}-1$ ）

Case 2：C［1］＝ 1
To formally state out the criteria，
－There are $\left(N-R_{1}\right)$ unblocked students（including column 1）
－Each of their $\left(N-R_{1}\right)$ columns must not form an inequality loop with column 1
$\Rightarrow$ Necessary condition：

$$
F=\Sigma C_{j}=\#\left(C_{j}=1\right) \geq N-R_{1}
$$



## Full Solution

－Handle $R_{1}=R_{2}=-1$
－Handle $R_{1}=R_{2}$
（Subtasks 3\＆4）
（Subtask 5）
－If $R_{1}>R_{2}$ ：
－Swap $R_{1}$ and $R_{2}$ ，flip each $C_{j}$ and $F$
－Handle $R_{1}<R_{2}$ ：
－If $R_{2} \leq \mathrm{N}$－2：Always possible
（Subtask 6）
－Else $\mathrm{R}_{2}=\mathrm{N}-1$
－If $\mathrm{F} \geq \mathrm{N}-\mathrm{R}_{1}$ ：Possible
－If $F<N-R_{1}$ ：Impossible
Score： 100
Time Complexity：O（N）

## Conclusion

－This is a Construction Task
－Case handling
－No fancy algorithms or data structures
－Search for patterns／structures for easier output generation
－Delegate jobs to helper functions for cleaner code
－Think outside the＂box＂
－Visualisation for better understanding
－Visualise the problem and samples
－Visualise your concepts and thoughts

