1. Absolute data (read in the « *config_file* »)

Loop **i** on all the lines: **ABSOLUT** station measure error
adjust.adata[] updated

adjust.adata[i].sta = station
adjust.adata[i].mes = measure
adjust.adata[i].err = error
adjust.adata[i].rei = 0

adjust.adjinfo.iabstot is the total absolute measures

2. Relative data (read in the « *config_file* »)

Loop **i** on all the lines: **IRELFIL** file
adjust.adjinfo.cfg_in_rdata[i] updated
adjust.adjinfo.r_ftotal is the total relative measures

3. Relative data (reading of « c » or « r » files from CG6TOOL

*For simplification, deletion of the term « **adjust** » in the rest of the document*

3.1. Loop on all file of adjinfo.cfg_in_rdata[ ]

- Search for the current gravimeter in the **adjinfo.r_gid[i]** table
  - Not found = **NEW**

    gc = **adjinfo.r_gtotal** // current gravimeter index
    adjinfo.r_gid[gc] **= gid** // current gravimeter identifier
    adjinfo.r_sbyg[gc] **= 0** // number of stations for the current gravimeter
    adjinfo.r_rbyg[gc] **= 0** // number of files for the current gravimeter
    s_total_curr = 0
    s_uniq_curr = 0

  - Found

    gc = **i** // current gravimeter index
    s_total_curr = adjinfo.r_sbyg[gc] // number of stations
    s_uniq_curr = adjinfo.r_sutot[gc] // number of unique stations

- Loop ***nbsta*** on all stations of the file and **rdata[]** updated

  j = s_total_curr + nbsta

  rdata[j][gc].id = gid
  rdata[j][gc].tra = adjinfo.r_rbyg[gc] // profile number
  rdata[j][gc].sta = current station
  rdata[j][gc].mes = $g_i - g_0$
  rdata[j][gc].err = current error

  If new station :

    - **adjinfo.r_sunum[s_uniq_curr][gc]** = current station
    - **s_uniq_curr**++

- **rinfo[][]** update

adjinfo.r_sbyg[gc**] =** adjinfo.r_sbyg[gc] + nbsta // stations counter
adjinfo.r_sbyr[adjinfo.r_rbyg[gc]][gc**] =** nbsta // stations/profile counter
adjinfo.r_sutot[gc**] =** s_uniq_curr // unique stations counter
adjinfo.r_rbyg[gc**]** = adjinfo.r_rbyg[gc] + 1 // profile counter
adjinfo.r_ototal[gc**] =** adjinfo.r_ototal[gc] + nbsta // observations counter

3.2. Unique stations counter

- Loop **ig** on all the gravimeters (**adjinfo.r_gtotal**)
  - Loop on all the stations of the current gravimeter **ns** = **adjinfo.r_sutot[ig]**
    - **adjinfo.r_usta[sta_total][]** update
- **adjinfo.r_stotal** = sta_total // total number of stations

3.3. Count of repetition by station

- Loop **ig** on all the gravimeters (**adjinfo.r_gtotal**)
  - Loop on all the stations of the current gravimeter **nbs** = **adjinfo.r_sbyg[ig]**
    - tc = **rdata[nbs][ig].tra** // Current profile
    - nbs_tc = **adjinfo.r_sbyr[tc][ig]** // number of station of the current profile
    - Loop on all the stations of the current profile : nbs → nbs + nbs_tc
      - If repetition then **adjinfo.r_usta[j][1]++**

3.4. Examples

ftes1c16.061 : (profile 1 / Gravi 1) : 9 9 9 35 35 500 500 35 35 9 9
ftes1c16.062 : (profile 2 / Gravi 1) : 9 9 500 500 355 355 9 9
ftes2c16.061 : (profile 3 / Gravi 2) : 9 9 9 35 35 600 600 35 9 9
ftes2c16.062 : (profile 4 / Gravi 2) : 35 35 500 500 35 35
ftes1c16.063 : (profile 5 / Gravi 1) : 35 35 600 600 35 35

adjust.adjinfo.cfg_in_rdata[0] = « ftes1c16.061 »
adjust.adjinfo.cfg_in_rdata[1] = « ftes1c16.062 »
adjust.adjinfo.cfg_in_rdata[2] = « ftes2c16.061 »
adjust.adjinfo.cfg_in_rdata[3] = « ftes2c16.062 »
adjust.adjinfo.cfg_in_rdata[4] = « ftes1c16.063 »

adjust.adjinfo.r_ftotal = 5 // Total number of files (profiles)

- <u>Reading the first file : profile 1 / Gravimeter 1</u>
  New gravimeter then ***gc*** = **adjinfo.r_gtotal = 0**
  adjinfo.r_gid[0**] = gid** // current gravimeter identifier
  adjinfo.r_sbyg[0**] = 0** // number of stations for the current gravimeter initialized
  adjinfo.r_rbyg[0**] = 0** // number of files for the current gravimeter initialized
  s_total_curr = 0 // total number of stations initialized
  s_uniq_curr = 0 // total number of unique stations initialized
  adjinfo.r_gtotal = 1 // total number of gravimeters updated
  - <u>Reading line 1 of the file 1</u>

  - Current station = 9
  - First measure (**nbsta=0**) then I save $\mathbf{g_0}$
  - i = **s_total_curr + nbsta = 0**
  - **rdata[0][0].id = 1**
    rdata[0][0].tra = adjinfo.r_rbyg[0] = 0
    rdata[0][0].sta = 9
    rdata[0][0].mes = $g_0 - g_0 = 0$
    rdata[0][0].err = $\sqrt{(e_0)^2+(e_0)^2} = e_0\sqrt{2}$
  - New station : **adjinfo.r_sunum[0][0] = 9** et **s_uniq_curr = 1**
  - **nbsta = 1**
- Reading line 2 of the file 1
  - Current station = 9
  - i = **s_total_curr + nbsta = 1**
  - **rdata[1][0].id = 1**
    rdata[1][0].tra = adjinfo.r_rbyg[0] = 0
    rdata[1][0].sta = 9
    rdata[1][0].mes = $g_1 - g_0$
    rdata[1][0].err = $\sqrt{(e_0)^2+(e_1)^2}$
  - Old station
  - **nbsta = 2**
- Reading line 3 of the file 1
  - Current station = 9
  - i = **s_total_curr + nbsta = 2**
  - **rdata[2][0].id = 1**
    rdata[2][0].tra = adjinfo.r_rbyg[0] = 0
    rdata[2][0].sta = 9
    rdata[2][0].mes = $g_2 - g_0$
    rdata[2][0].err = $\sqrt{(e_0)^2+(e_2)^2}$
  - Old station
  - **nbsta = 3**
- Reading line 4 of the file 1
  - Current station = 35
  - i = **s_total_curr + nbsta = 3**
  - **rdata[3][0].id = 1**
    rdata[3][0].tra = adjinfo.r_rbyg[0] = 0
    rdata[3][0].sta = 35
    rdata[3][0].mes = $g_3 - g_0$
    rdata[3][0].err = $\sqrt{(e_0)^2+(e_3)^2}$
  - New station : **adjinfo.r_sunum[1][0] = 35** et **s_uniq_curr = 2**
  - **nbsta = 4**

- Readin the last line (line 11) of the file 1
  - Current station = 9
  - i = **s_total_curr + nbsta = 10**
  - **rdata[10][0].id = 1**
    rdata[10][0].tra = adjinfo.r_rbyg[0] = 0
    rdata[10][0].sta = 9
    rdata[10][0].mes = $g_{10} - g_0$
    rdata[10][0].err = $\sqrt{(e_0)^2+(e_{10})^2}$
  - Old station
  - **nbsta = 11**
- End of the file (profile) : **adjinfo** update
  - **adjinfo.r_sbyg**[0] **= adjinfo.r_sbyg**[0] **+ nbsta = 11** // stations/gravi
  - **adjinfo.r_sbyr**[0][0] **= nbsta = 11** // station/profile
  - **adjinfo.r_sutot**[0] **= s_uniq_curr = 3** // unique stations/gravi
  - **adjinfo.r_rbyg**[0] **= adjinfo.r_rbyg**[0] **+ 1 = 1** // profiles
  - **adjinfo.r_ototal = adjinfo.r_ototal + nbsta = 11** // observations

	0	1	2	3	4	5	6	7	8	9	10
rdata[ ][0].sta	9	9	9	35	35	500	500	35	35	9	9
rdata[ ][0].mes	**0**	g_1-g_0	g_2-g_0	g_3-g_0	g_4-g_0	g_5-g_0	g_6-g_0	g_7-g_0	g_8-g_0	g_9-g_0	$g_{10}-g_0$

adjinfo.r_sunum[ ][0]	9	35	500

- Reading of the second file : profile 2 / Gravimeter 1

  Old gravimeter with ***gc*** = **0**

  s_total_curr = adjinfo.r_sbyg[0] **= 11** // Total stations initialized

  s_uniq_curr = adjinfo.r_sutot[0] **= 3** // Unique stations initialized

  - End of file 2 (profile 2) : **adjinfo** update
    - **adjinfo.r_sbyg**[0] **= adjinfo.r_sbyg**[0] **+ nbsta = 11 + 8 = 19**
    - **adjinfo.r_sbyr**[1][0] **= nbsta = 8** // station/profile
    - **adjinfo.r_sutot**[0] **= s_uniq_curr = 4** // unique stations /gravi
    - **adjinfo.r_rbyg**[0] **= adjinfo.r_rbyg**[0] **+ 1 = 1 + 1 = 2** // profiles
    - **adjinfo.r_ototal = adjinfo.r_ototal + nbsta = 19** // observations

	0		10	11	12	13	14	15	16	17	18
rdata[ ][0].sta	9		9	9	9	500	500	355	355	9	9
rdata[ ][0].mes	**0**		$g_{10}-g_0$	**0**	$g_{12}-g_{11}$	$g_{13}-11$	$g_{14}-g_{11}$	$g_{15}-g_{11}$	$g_{16}-g_{11}$	$g_{17}-g_{11}$	$g_{18}-g_{11}$

adjinfo.r_sunum[ ][0]	9	35	500	355

- Reading the third file : Profile 3 / Gravimeter 2
  New gravimeter then ***gc*** = **adjinfo.r_gtotal = 1**
  adjinfo.r_gid[1] **= gid** // current gravimeter identifier
  adjinfo.r_sbyg[1] **= 0** // number of stations for the current gravimeter initialized
  adjinfo.r_rbyg[1] **= 0** // number of files for the current gravimeter initialized
  s_total_curr = 0 // total number of stations initialized
  s_uniq_curr = 0 // total number of unique stations initialized
  adjinfo.r_gtotal = 2 // total number of gravimeters updated

  - End of the file 3 (profile 3) : **adjinfo** updated
    - **adjinfo.r_sbyg**[1] **= adjinfo.r_sbyg**[1] **+ nbsta = 0 + 10 = 10**
    - **adjinfo.r_sbyr**[0][1] **= nbsta = 10** // station/profile
    - **adjinfo.r_sutot**[1] **= s_uniq_curr = 3** // unique stations /gravi
    - **adjinfo.r_rbyg**[1] **= adjinfo.r_rbyg**[1] **+ 1 = 0 + 1 = 1** // profiles
    - **adjinfo.r_ototal = adjinfo.r_ototal + nbsta = 29** // observations

	0	1	2	3	4	5	6	7	8	9
rdata[ ][1].sta	9	9	9	35	35	600	600	35	9	9
rdata[ ][1].mes	**0**	g_1-g_0	g_2-g_0	g_3-g_0	g_4-g_0	g_5-g_0	g_6-g_0	g_7-g_0	g_8-g_0	g_9-g_0

adjinfo.r_sunum[ ][1]	9	35	600

- Reading of the last file : profile 5 / Gravimeter 1
  Old gravimeter withe ***gc*** = **0**
  s_total_curr = adjinfo.r_sbyg[0] **= 18** // Total stations initialized
  s_uniq_curr = adjinfo.r_sutot[0] **= 4** // Unique stations initialized

  - End of file 5 (profile 5) : **adjinfo** updated
    - **adjinfo.r_sbyg**[0] **= adjinfo.r_sbyg**[0] **+ nbsta = 18 + 6 = 25**
    - **adjinfo.r_sbyr**[2][0] **= nbsta = 6** // station/profile
    - **adjinfo.r_sutot**[0] **= s_uniq_curr = 5** // unique stations/gravi
    - **adjinfo.r_rbyg**[0] **= adjinfo.r_rbyg**[0] **+ 1 = 2 + 1 = 3** // profiles
    - **adjinfo.r_ototal = adjinfo.r_ototal + nbsta = 41** // observations

	0		9	10	11		15	16	17	18	19		24
rdata[ ][0].sta	9		9	9	9		9	35	355	9	35		35
rdata[ ][1].sta	9		9	35	35		15						

adjinfo.r_sunum[ ][0]	9	35	500	355	600
adjinfo.r_sunum[ ][1]	9	35	600	500	

- End of files reading : 5 Profiles / 2 Gravimeters
  - **adjinfo.r_ototal** = 41 // Total Observations
  - **adjinfo.r_gtotal** = 2 // Gravimeters used
  - **adjinfo.r_stotal** = 5 // Total unique stations
  - **adjinfo.r_rbyg[ ]** // Profiles (files) by gravimeter

    adjinfo.r_rbyg[0] = 3
    adjinfo.r_rbyg[1] = 2
  - **adjinfo.r_sbyg[ ]** // Stations by gravimeter

    adjinfo.r_sbyg[0] = 25
    adjinfo.r_sbyg[1] = 16
  - **adjinfo.r_sbyr[ ][ ]** // Number of stations by profile

adjinfo.r_sbyr[ ][0]	11	8	6
adjinfo.r_sbyr[ ][1]	10	6	

  - **adjinfo.r_sutot[ ]** // Number of unique stations by profile

    adjinfo.r_sutot[0] = 5
    adjinfo.r_sutot[1] = 4
  - **adjinfo.r_sunum[ ][ ]** // Unique stations number by gravimeter

adjinfo.r_sunum[ ][0]	9	35	500	355	600
adjinfo.r_sunum[ ][1]	9	35	600	500	

  - **rdata[ ][ ]** // Observations (*sta, trav, gid, mes, err, rei, réo*)

rdata[ ][0]	Profile 1 / Gravi 1	Profile 2 / Gravi 1	Profile 5 / Gravi 1
rdata[ ][1]	Profile 3 / Gravi 2	Profile 4 / Gravi 2	

  - **adjinfo.r_usta[ ][ ]** // Unique stations of the field campaign

adjinfo.r_usta[ ][0]	9	35	500	355	600	Number

4. Determination of calibration coefficients (Scaling factors)

- ✓ Illustration of the calculation with the example above :
  Reference Gravimeter **Gr**: G_0 / 3 profiles (***.r_rbyg[0]***) / 25 stations (***.r_sbyg[0]***)
  Gravimeter to calibrate **Gc**: G_1 / 2 profiles (***.r_rbyg[1]***) / 16 stations (***.r_sbyg[1]***)

- ✓ <u>Step 1 : Recuperation of all the profiles of the **Gc** gravimeter to calibrate</u>
  nbt is the number of profile for the gravimeter ***g***, ***nbst***$_i$ the number of station of the profile t_i with **g** and $\boldsymbol{\Delta seg_{max}}$ the final number of segment for ***g***.
  For each profile ***i*** *realized with the gravimeter* ***g*** : ***nbst***$_i$ = adjinfo.r_sbyr[**t**$_i$][**g**]

$$\boldsymbol{\Delta seg_{max}} = \sum_{i=0}^{nbt-1} \left(\sum_{j=1}^{nbsti-1} j \right)$$

For the gravimeter G_1 : $\boldsymbol{\Delta seg_{max}} =$ Σ(10-1) + Σ(6-1) = 45+15 = 60 segments

At the end we have an array with for each segment **(s1-s2)**:

- the <u>index</u> (in **.r_usta[ ][ ]**) of the stations s1 et s2,
- the <u>difference</u> ($g_{end}-g_{begin}$) and the associate <u>error</u> ($\sqrt{\,(\mathbf{e_{end}})^2+(\mathbf{e_{begin}})^2}$).

adjinfo.r_usta[ ][0]	9	35	500	355	600	Number
	0	1	2	3	4	Index

rdata[ ][1.sta	9	9	9	35	35	600	600	35	9	9	35	35	500	500	35	35
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

	Δ Si–S0									Δ Si–S1								Δ S9–S8	Δ Si–S10					Δ Si–S11				Δ S15–S14		
Gcal_s1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	2	1
Gcal_s2	0	0	1	1	4	4	1	0	0	0	1	1	4	4	1	0	0	0	1	2	2	1	1	2	2	1	1	1	1	1
Gcal_co	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
					4	5								12	13															

- ✓ <u>Step 2 : The duplicate segments are averaged for the gravimeter **Gc** to calibrate</u>

  Loop for all the segments in order to average the duplicates.

Gcal_s1	**0**	**0**	**0**	**1**	**1**	**1**	**4**	**4**	**1**	**2**
Gcal_s2	**0**	**1**	**4**	**1**	**4**	**0**	**1**	**0**	**2**	**1**
Stations	**9:9**	**9:35**	**9:600**	**35:35**	**35:600**	**35:9**	**600:35**	**600:9**	**35:500**	**500:35**

For each segment ***j*** identical and ***n*** the number of duplicate segments

- **n > 1 :** $\overline{\Delta Gc_j} = \frac{\sum_1^N w_i \Delta Gc_i}{\sum_1^N w_i} \quad \left(w_i = \frac{1}{\Delta Ec_i^2} \right)$ *et* $\overline{\Delta Ec_j} = \sqrt{\frac{\sum_1^N w_i \Delta Gc_i^2}{\sum_1^N w_i} - \overline{\Delta Gc_j^2}}$
- **n = 1 :** $\overline{\Delta Gc_j} = \Delta Gc_j$ **et** $\overline{\Delta Ec_j} = \Delta Ec_j$

- ✓ <u>Step 3 and 4 : same processing with the reference gravimeter **Gr**</u>

✓ Step 5 : Linear relation between the two gravimeters

The purpose of this step is to calculate **k** such that **k*Gc = Gr** using a Least-square method. We search a straight line that minimize the sum of the squares of the residual values (Gr – k*Gc – b). Each element of the sum is weighted by the weight $\mathbf{w_i = 1 / ((\Delta Ec_i)^2 + (\Delta Er_i)^2)}$

- Matrix generation and resolution of the obtained system (**PASS 1**) :

$$[\,W\,] \times \begin{vmatrix} \Delta Gc_1 & 1 \\ \Delta Gc_2 & 1 \\ . & . \\ . & . \\ . & . \\ \Delta Gc_n & 1 \end{vmatrix} \times \begin{vmatrix} k_1 \\ \\ b_1 \end{vmatrix} = [\,W\,] \times \begin{vmatrix} \Delta Gr_1 \\ \Delta Gr_2 \\ . \\ . \\ . \\ \Delta Gr_n \end{vmatrix}$$

  At the end of **PASS 1** we obtain the calibration coefficients ($\mathbf{k_1}$, $\mathbf{b_1}$) as well as the **standard deviation** $\boldsymbol{\sigma_1}$ for the residuals.

- Removal of isolated points ($\mathbf{rési_i} > 3\boldsymbol{\sigma_{i-1}}$) : (**PASS 2 – PASS 20**)

  20 iterations with deletion of data whose residue is greater than three times the standard deviation calculated during the previous iteration.

  The information is displayed on the screen.

- Determination of the final calibration coefficient **k**

  Use of the remaining data to calculate the parameter k of the line passing through the origin (b=0).

5. Adjustment of all data (Adjustment)

- ✓ Step 1 : Recovery of "user" $\mathbf{k_g}$ coefficients of each gravimeter
- ✓ Step 2 : Value estimation for the first station (base) of each profile (file)
  - Loop of all absolutes stations read in the *config_file* and stored in **adata[]**. The stations used in the adjustment (stored in **r_usta[ ][0]**) allow to build the C, B and W matrices :

adata[ ].sta	Sa_0	Sa_1	Sa_i	Sa_{n-1}	**n** absolute sites
adata[ ].mes	Ga_0	Ga_1	Ga_i	Ga_{n-1}	
adata[ ].err	Ea_0	Ea_1	Ea_i	Ea_{n-1}	

r_usta[ ][0]	S_0	S_1	S_j	S_{m-1}	**m** adjusted stations

If all the absolute values are used in the adjustment then the value read in **adata[i]** (station in **r_usta[j]**) will cause the update of the following cells (**i-th** column of A array) :

$$C[i][j] = 1 \; ; \; B[i] = Ga_i \; ; \; W[i][i] = 1/(Ea_i)^2$$

  - Loop of all relative stations stored in **rdata[]**.
    - ➢ The segment [**S1(i):S1(j)]** (repetition/reoccupation) will be use only if **S1** is an absolute site (**adata[ii]**) with index **jj** in **r_usta[]** :

> ***ind*** = current index
> ***Kc*** = current calibration coefficient
>
> m1 = rdata[i].mes ; e1 = rdata[i].err
> m2 = rdata[j].mes ; e2 = rdata[j].err
>
> **C[*ind*][jj] = 1 ;**
>
> **B[*ind*] =** $\mathbf{Ga_{ii}}$ **+ (m2 – m1) * *Kc***
>
> **W[*ind*][*ind*] = 1 / ((e2)² + (e1)²)**

    - ➢ Segment [**S1(i):S2(j)]**. The station **S1** (**S2**) have an index **ii** (**jj** respectively) in **r_usta[]**

> ***ind*** = current index
> ***Kc*** = current calibration coefficient
>
> m1 = rdata[i].mes ; e1 = rdata[i].err
> m2 = rdata[j].mes ; e2 = rdata[j].err
>
> **C[*ind*][ii] = -1 ; C[*ind*][jj] = 1 ;**
>
> **B[*ind*] = (m2 – m1) * *Kc***
>
> **W[*ind*][*ind*] = 1 / ((e2)² + (e1)²)**

  - Determination of the linar system : **[W] [C] [X] = [W] [B]**

- ✓ Step 3 : Determination of a value for all the stations in the network
  - If the first station of a profile is unknown (because it's not an absolute site) then stations are undetermined and another calculation is automatically realized.
    - ➢ Segment **[S1:S1]** with **S1** absolute site : same above
    - ➢ Segment **[S1(i):S1(j)]** (**S1** adjusted site in step 2) :

ind = current index ***Kc*** = current calibration coefficient m1 = rdata[i].mes ; e1 = rdata[i].err m2 = rdata[j].mes ; e2 = rdata[j].err $\mathbf{G_{adj}}$ = Value for S1 obtained in step 2 $\mathbf{e_{adj}}$ = Error for S1 obtained in step 2 **C[*ind*][jj] = 1 ;** **B[*ind*] =** $\mathbf{G_{adj}}$ **+ (m2 – m1) * *Kc*** **W[*ind*][*ind*] = 1 / ((e2)² + (e1)² + ($\mathbf{e_{adj}}$)²)**

    - ➢ Segment **[S1(i):S2(j)]** : same above

- ✓ Step 4 : Data filtering (Option)

  Another iteration is realized if the keyword **ADJNSIG** is activate in the *config_file*.

  All the observations with residues biggest than **ADJNSIG * σ** are eliminated.

6. Summary

In each site **S** of a profile we have measured with a gravimeter ***m*** the gravity **g** (with an error **e**). ($\mathbf{g_0}$, $\mathbf{e_0}$) is the first measure for the base $\mathbf{S_0}$ (first station). ($\mathbf{g_i}$, $\mathbf{e_i}$) is the measure for the station $\mathbf{S_i}$.

- ✓ Calculation of all the segments **So-Si** : $\Delta g_i = g_i - g_0$, $E_i \sqrt{((e_0)^2+(e_i)^2)}$
- ✓ Duplicate segments (**n**) are averaged : $\overline{\Delta g}_i$, $\overline{\Delta E}_i$
- ✓ Calculation of the calibration coefficient $K_m \mid G_{ref} = K_m * G_m$
- ✓ Adjustment of all the network stations (absolutes and relatives data)
  - The absolutes measures (a_i, e_i) are weighted by $1/(e_i)^2$
  - The segments **Si**[g_i,e_i]:**Sj**[g_j,e_i] with $i \neq j$ are weighted by $1/((e_i)^2+(e_j)^2)$
  - The segments **Sn**[g_i,e_i]:**Sn**[g_j,e_i] (with **Sn** no absolute) are weighted by $1/((e_i)^2+(e_j)^2+(\sigma_n)^2)$ with σ_n (standard deviation) obtained for **Sn** in step 2.