```
(* Pseudomonas putida (P. putida) -- Null space analysis *)

In[1]:= (* List of metabolite identifiers *)
metaboliteIds = {"2dda7p_c", "2ddg6p_c", "2dhglcn_c", "34dhbz_c", "3dhq_c",
    "3dhsk_c", "3pg_c", "6p2dhglcn_c", "6pgc_c", "ac_c", "acald_c", "accoa_c",
    "acon_c", "actp_c", "adp_c", "akg_c", "amp_c", "atp_c", "catechol_c",
    "ccmuac_c", "cit_c", "co2_c", "coa_c", "dhap_c", "e4p_c", "etoh_c", "f6p_c",
    "fdp_c", "fum_c", "g3p_c", "g6p_c", "glc__D_c", "glcn_c", "gln__L_c",
    "glu__L_c", "glx_c", "glyc3p_c", "glyc_c", "h2o_c", "h_c", "hco3_c", "icit_c",
    "lac__D_c", "mal__L_c", "nad_c", "nadh_c", "nadp_c", "nadph_c", "nh4_c",
    "o2_c", "oaa_c", "pep_c", "pi_c", "pyr_c", "q8_c", "q8h2_c", "r5p_c",
    "ru5p__D_c", "s7p_c", "succ_c", "xu5p__D_c", "ac_e", "acald_e", "akg_e",
    "co2_e", "fum_e", "glc__D_e", "gln__L_e", "glu__L_e", "glyc_e", "h2o_e", "h_e",
    "lac__D_e", "mal__L_e", "nh4_e", "o2_e", "pi_e", "pyr_e", "succ_e", "toh_e"};
(* List of reaction identifiers *)
reactionIds = {"3-DEHYDROQUINATE-DEHYDRATASE-RXN$r", "ACALD$r", "ACALDt$r",
    "ACKr$r", "ACONTa$r", "ACONTb$r", "ALCD2x$r", "ATPS4r$r", "CO2t$r",
    "CS$r", "DAHPSYN-RXN$r", "ENO$r", "ETOHt2r$r", "EX_co2_e$r", "EX_glc_e$r",
    "EX_h2o_e$r", "EX_h_e$r", "EX_nh4_e$r", "EX_o2_e$r", "EX_pi_e$r",
    "FBA$r", "FRD7$r", "FUM$r", "GAPD$r", "GLUDy$r", "GLYCT$r", "H2Ot$r",
    "HCO3E$r", "ICDHyr$r", "ICL$r", "MDH$r", "NADTRHD$r", "NH4t$r", "O2t$r",
    "PDH$r", "PGI$r", "PGLCNDH$r", "PROTOCATECHUATE-DECARBOXYLASE-RXN$r",
    "PTAr$r", "PYRt2$r", "RPE$r", "RPI$r", "TALA$r", "TKT1$r", "TKT2$r",
    "TPI$r", "XYLA$r", "2DHGLCK$f", "3-DEHYDROQUINATE-DEHYDRATASE-RXN$f",
    "3-DEHYDROQUINATE-SYNTHASE-RXN$f", "ACALD$f", "ACALDt$f", "ACKr$f", "ACONTa$f",
    "ACONTb$f", "ACt2r$f", "ADK1$f", "AKGDH$f", "AKGt2r$f", "ALCD2x$f", "ATPM$f",
    "ATPS4r$f", "Biomass_Ecoli_core_w_GAM$f", "CATECHOL-12-DIOXYGENASE-RXN$f",
    "CO2t$f", "CS$f", "CYTBD$f", "DAHPSYN-RXN$f", "DHSHIKIMATE-DEHYDRO-RXN$f",
    "D_LACt2$f", "ENO$f", "ETOHt2r$f", "EX_ac_e$f", "EX_acald_e$f", "EX_akg_e$f",
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    "EX_succ_e$f", "EX_xyl_e$f", "FBA$f", "FBP$f", "FRD7$f", "FUM$f", "FUMt2_2$f",
    "G3PD$f", "G6PDH2r$f", "GADktpp$f", "GAPD$f", "GLCDpp$f", "GLCabcpp$f",
    "GLNS$f", "GLNabc$f", "GLUDy$f", "GLUN$f", "GLUSy$f", "GLUt2r$f", "GLYCT$f",
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    "ICL$f", "KDPGALDOL$f", "LDH_D$f", "MALS$f", "MALt2_2$f", "MDH$f", "ME1$f",
    "ME2$f", "NADH16$f", "NADTRHD$f", "NH4t$f", "O2t$f", "PC$f", "PDH$f",
    "PGI$f", "PGL$f", "PGLCNDH$f", "PGLUCONDEHYDRAT$f", "PIt2r$f", "PPC$f",
    "PPCK$f", "PROTOCATECHUATE-DECARBOXYLASE-RXN$f", "PTAr$f", "PYK$f",
    "PYRt2$f", "RPE$f", "RPI$f", "SUCCt2_2$f", "SUCCt3$f", "TALA$f", "THD2$f",
    "TKT1$f", "TKT2$f", "TPI$f", "XYLA$f", "XYL_ABC$f", "muconate_sink$f"};
(* Matrix of stoichiometric coefficients
 (Rows=Metabolites; Columns=Reactions) *)
stoichiometryMatrix = {{0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0,
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     0, 0, 0, 0, 0, 0, 0, 0, 0, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
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     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, 0, 0, 0, 0, 0, 0, 0, 0, -1, 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, 0, 0, 0, 0, 0, 0, 0, 0, 0,
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    {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, 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, 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, 0, 0, 0, 0, -1, 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, 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, -1, 1, 0, 0, 0, 0, 0, 0, 0, 0},
    {0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 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, 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, 0, 0, 0, 0, 0, 0, 0, 0, -1, 0, 0, 0, 0, -1,
     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, 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, 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, 0, 0, 0, 0, 0, 0}};
(* Numerical tolerance, viz., the neighborhood of zero with
 respect to the matrix of stoichiometric coefficients. *)
tolerance = Times[Max[Dimensions[stoichiometryMatrix]],
   $MachineEpsilon, Norm[stoichiometryMatrix, Infinity]];
(* Extracellular metabolites are denoted by the "_e" suffix. *)
extracellularMetaboliteIds =
  Select[metaboliteIds, Function[string, Last[StringSplit[string, "_"]] == "e"]];
(* Intracellular metabolites are denoted by the "_c" suffix. *)
intracellularMetaboliteIds =
  Select[metaboliteIds, Function[string, Last[StringSplit[string, "_"]] == "c"]];
(* The block of the matrix of stoichiometric coefficients
 for extracellular metabolites only. *)
extracellularStoichiometryMatrix =
  Drop[stoichiometryMatrix, Length[intracellularMetaboliteIds]];
(* The block of the matrix of stoichiometric coefficients
 for intracellular metabolites only. *)
intracellularStoichiometryMatrix =
  Take[stoichiometryMatrix, Length[intracellularMetaboliteIds]];
(* The "null space" of the block of the matrix of stoichiometric
 coefficients for intracellular metabolites only. *)
intracellularNullspaceMatrix = Transpose[
   RowReduce[NullSpace[intracellularStoichiometryMatrix], Tolerance → tolerance]];

(* Print the matrix of stoichiometric coefficients. *)
```

```
Dimensions[stoichiometryMatrix]
MatrixForm[stoichiometryMatrix, TableHeadings → {metaboliteIds, reactionIds}]
```

Out[10]= {80, 154}

Out[11]//MatrixForm=

	3-DEHYDROQUINATE-DEHYDRATASE-RXN$r	ACALD$r	ACALDt$r	ACKr$r	ACONTa$r	A
2dda7p_c	0	0	0	0	0	
2ddg6p_c	0	0	0	0	0	
2dhglcn_c	0	0	0	0	0	
34dhbz_c	0	0	0	0	0	
3dhq_c	1	0	0	0	0	
3dhsk_c	-1	0	0	0	0	
3pg_c	0	0	0	0	0	
6p2dhglcn_c	0	0	0	0	0	
6pgc_c	0	0	0	0	0	
ac_c	0	0	0	1	0	
acald_c	0	1	-1	0	0	
accoa_c	0	-1	0	0	0	
acon_c	0	0	0	0	-1	
actp_c	0	0	0	-1	0	
adp_c	0	0	0	-1	0	
akg_c	0	0	0	0	0	
amp_c	0	0	0	0	0	
atp_c	0	0	0	1	0	
catechol_c	0	0	0	0	0	
ccmuac_c	0	0	0	0	0	
cit_c	0	0	0	0	1	
co2_c	0	0	0	0	0	
coa_c	0	1	0	0	0	
dhap_c	0	0	0	0	0	
e4p_c	0	0	0	0	0	
etoh_c	0	0	0	0	0	
f6p_c	0	0	0	0	0	
fdp_c	0	0	0	0	0	
fum_c	0	0	0	0	0	
g3p_c	0	0	0	0	0	
g6p_c	0	0	0	0	0	
glc__D_c	0	0	0	0	0	
glcn_c	0	0	0	0	0	
gln__L_c	0	0	0	0	0	
glu__L_c	0	0	0	0	0	
glx_c	0	0	0	0	0	
glyc3p_c	0	0	0	0	0	
glyc_c	0	0	0	0	0	
h2o_c	-1	0	0	0	-1	
h_c	0	-1	0	0	0	
hco3_c	0	0	0	0	0	
icit_c	0	0	0	0	0	
lac__D_c	0	0	0	0	0	
mal__L_c	0	0	0	0	0	
nad_c	0	1	0	0	0	

nadh_c	0	−1	0	0	0
nadp_c	0	0	0	0	0
nadph_c	0	0	0	0	0
nh4_c	0	0	0	0	0
o2_c	0	0	0	0	0
oaa_c	0	0	0	0	0
pep_c	0	0	0	0	0
pi_c	0	0	0	0	0
pyr_c	0	0	0	0	0
q8_c	0	0	0	0	0
q8h2_c	0	0	0	0	0
r5p_c	0	0	0	0	0
ru5p__D_c	0	0	0	0	0
s7p_c	0	0	0	0	0
succ_c	0	0	0	0	0
xu5p__D_c	0	0	0	0	0
ac_e	0	0	0	0	0
acald_e	0	0	1	0	0
akg_e	0	0	0	0	0
co2_e	0	0	0	0	0
fum_e	0	0	0	0	0
glc__D_e	0	0	0	0	0
gln__L_e	0	0	0	0	0
glu__L_e	0	0	0	0	0
glyc_e	0	0	0	0	0
h2o_e	0	0	0	0	0
h_e	0	0	0	0	0
lac__D_e	0	0	0	0	0
mal__L_e	0	0	0	0	0
nh4_e	0	0	0	0	0
o2_e	0	0	0	0	0
pi_e	0	0	0	0	0
pyr_e	0	0	0	0	0
succ_e	0	0	0	0	0
toh_e	0	0	0	0	0

In[12]:=
```
(* Print the "null space",
then replace values in the neighborhood of zero with zero. *)
Dimensions[intracellularNullspaceMatrix]
MatrixForm[intracellularNullspaceMatrix, TableHeadings → {reactionIds}]
MatrixForm[intracellularNullspaceMatrix /. x_ /; (Abs[x] ≤ tolerance) → 0,
 TableHeadings → {reactionIds}]
```

Out[12]= {154, 98}

Out[13]//MatrixForm=

A very large output was generated. Here is a sample of it:

(<<1>>)

Show Less | Show More | Show Full Output | Set Size Limit...

Out[14]//MatrixForm=

3-DEHYDROQUINATE-DEHYDRATASE-RXN$r	1	0	0	0	0	0
ACALD$r	0	1	0	0	0	0
ACALDt$r	0	0	1	0	0	0
ACKr$r	0	0	0	1	0	0
ACONTa$r	0	0	0	0	1	0
ACONTb$r	0	0	0	0	0	1
ALCD2x$r	0	0	0	0	0	0
ATPS4r$r	0	0	0	0	0	0
CO2t$r	0	0	0	0	0	0
CS$r	0	0	0	0	0	0
DAHPSYN-RXN$r	0	0	0	0	0	0
ENO$r	0	0	0	0	0	0
ETOHt2r$r	0	0	0	0	0	0
EX_co2_e$r	0	0	0	0	0	0
EX_glc_e$r	0	0	0	0	0	0
EX_h2o_e$r	0	0	0	0	0	0
EX_h_e$r	0	0	0	0	0	0
EX_nh4_e$r	0	0	0	0	0	0
EX_o2_e$r	0	0	0	0	0	0
EX_pi_e$r	0	0	0	0	0	0
FBA$r	0	0	0	0	0	0
FRD7$r	0	0	0	0	0	0
FUM$r	0	0	0	0	0	0
GAPD$r	0	0	0	0	0	0
GLUDy$r	0	0	0	0	0	0
GLYCT$r	0	0	0	0	0	0
H2Ot$r	0	0	0	0	0	0
HCO3E$r	0	0	0	0	0	0
ICDHyr$r	0	0	0	0	0	0
ICL$r	0	0	0	0	0	0
MDH$r	0	0	0	0	0	0
NADTRHD$r	0	0	0	0	0	0
NH4t$r	0	0	0	0	0	0
O2t$r	0	0	0	0	0	0
PDH$r	0	0	0	0	0	0
PGI$r	0	0	0	0	0	0
PGLCNDH$r	0	0	0	0	0	0
PROTOCATECHUATE-DECARBOXYLASE-RXN$r	0	0	0	0	0	0
PTAr$r	0	0	0	0	0	0
PYRt2$r	0	0	0	0	0	0
RPE$r	0	0	0	0	0	0
RPI$r	0	0	0	0	0	0
TALA$r	0	0	0	0	0	0
TKT1$r	0	0	0	0	0	0
TKT2$r	0	0	0	0	0	0
TPI$r	0	0	0	0	0	0
XYLA$r	0	0	0	0	0	0
2DHGLCK$f	0	0	0	0	0	0
3-DEHYDROQUINATE-DEHYDRATASE-RXN$f	0	0	0	0	0	0
3-DEHYDROQUINATE-SYNTHASE-RXN$f	-1.	0	0	0	0	0
ACALD$f	0	0	0	0	0	0

ACALD$f	0	0	0	0	0	0
ACALDt$f	0	0	0	0	0	0
ACKr$f	0	0	0	0	0	0
ACONTa$f	0	0	0	0	0	0
ACONTb$f	0	0	0	0	-1.	1.
ACt2r$f	0	0	0	-1.	0	0
ADK1$f	0	0	0	0	0	0
AKGDH$f	0	0	0	0	0	0
AKGt2r$f	0	0	0	0	0	0
ALCD2x$f	0	-1.	1.	0	0	0
ATPM$f	0	0	0	0	0	0
ATPS4r$f	0	0	0	0	0	0
Biomass_Ecoli_core_w_GAM$f	0	0	0	0	0	0
CATECHOL-12-DIOXYGENASE-RXN$f	-1.	0	0	0	0	0
CO2t$f	0	0	0	0	0	0
CS$f	0	0	0	0	-1.	0
CYTBD$f	0	0	0	0	0	0
DAHPSYN-RXN$f	-1.	0	0	0	0	0
DHSHIKIMATE-DEHYDRO-RXN$f	-1.	0	0	0	0	0
D_LACt2$f	0	0	0	0	0	0
ENO$f	0	0	0	0	0	0
ETOHt2r$f	0	-1.	1.	0	0	0
EX_ac_e$f	0	0	0	0	0	0
EX_acald_e$f	0	0	0	0	0	0
EX_akg_e$f	0	0	0	0	0	0
EX_co2_e$f	0	0	0	0	0	0
EX_etoh_e$f	0	0	0	0	0	0
EX_fum_e$f	0	0	0	0	0	0
EX_glc_e$f	0	0	0	0	0	0
EX_gln__L_e$f	0	0	0	0	0	0
EX_glu__L_e$f	0	0	0	0	0	0
EX_glyc_e$f	0	0	0	0	0	0
EX_h2o_e$f	0	0	0	0	0	0
EX_h_e$f	0	0	0	0	0	0
EX_lac__D_e$f	0	0	0	0	0	0
EX_mal__L_e$f	0	0	0	0	0	0
EX_nh4_e$f	0	0	0	0	0	0
EX_o2_e$f	0	0	0	0	0	0
EX_pi_e$f	0	0	0	0	0	0
EX_pyr_e$f	0	0	0	0	0	0
EX_succ_e$f	0	0	0	0	0	0
EX_xyl_e$f	0	0	0	0	0	0
FBA$f	0	0	0	0	0	0
FBP$f	0	0	0	0	0	0
FRD7$f	0	0	0	0	0	0
FUM$f	0	0	0	0	0	0
FUMt2_2$f	0	0	0	0	0	0
G3PD$f	0	0	0	0	0	0
G6PDH2r$f	0	0	0	0	0	0
GAPktpp$f	0	0	0	0	0	0

GADKtpp$f	0	0	0	0	0	0
GAPD$f	0	0	0	0	0	0
GLCDpp$f	0	0	0	0	0	0
GLCabcpp$f	0	0	0	0	0	0
GLNS$f	0	0	0	0	0	0
GLNabc$f	0	0	0	0	0	0
GLUDy$f	0	0	0	0	0	0
GLUN$f	−1.	2.	−1.	0	1.	0
GLUSy$f	1.	−2.	1.	0	−1.	0
GLUt2r$f	−1.	2.	−1.	0	1.	0
GLYCT$f	0	0	0	0	0	0
GLYK$f	0	0	0	0	0	0
GND$f	−0.5	0	0	0	0	0
GNK$f	0	0	0	0	0	0
H2Ot$f	−0.5	4.	−2.	1.	0	0
HCO3E$f	0	0	0	0	0	0
HEX1$f	0	0	0	0	0	0
ICDHyr$f	1.	−2.	1.	0	−1.	0
ICL$f	−1.	2.	−1.	0	0	0
KDPGALDOL$f	−0.5	0	0	0	0	0
LDH_D$f	0	0	0	0	0	0
MALS$f	−1.	2.	−1.	0	0	0
MALt2_2$f	2.5	−3.	1.	−1.	1.	0
MDH$f	0	0	0	0	0	0
ME1$f	0	0	0	0	0	0
ME2$f	1.5	−1.	0	−1.	1.	0
NADH16$f	0	0	0	0	0	0
NADTRHD$f	0	0	0	0	0	0
NH4t$f	1.	−2.	1.	0	−1.	0
O2t$f	−1.	0	0	0	0	0
PC$f	0	0	0	0	0	0
PDH$f	−1.	3.	−1.	1.	−1.	0
PGI$f	0	0	0	0	0	0
PGL$f	−1.	0	0	0	0	0
PGLCNDH$f	0	0	0	0	0	0
PGLUCONDEHYDRAT$f	−0.5	0	0	0	0	0
PIt2r$f	1.	0	0	0	0	0
PPC$f	0	0	0	0	0	0
PPCK$f	0	0	0	0	1.	0
PROTOCATECHUATE-DECARBOXYLASE-RXN$f	−1.	0	0	0	0	0
PTAr$f	0	0	0	1.	0	0
PYK$f	1.	0	0	0	1.	0
PYRt2$f	−3.	4.	−1.	2.	−3.	0
RPE$f	0	0	0	0	0	0
RPI$f	0.5	0	0	0	0	0
SUCCt2_2$f	1.66667	−2.	0.666667	−0.333333	0.333333	0
SUCCt3$f	0.666667	0	−0.333333	−0.333333	0.333333	0
TALA$f	−0.5	0	0	0	0	0
THD2$f	−1.	1.	0	1.	−1.	0
TKT1$f	0.5	0	0	0	0	0
TKT2$f	0.5	0	0	0	0	0

TPI$f	0	0	0	0	0	0
XYLA$f	0	0	0	0	0	0
XYL_ABC$f	1.	0	0	1.	0	0
muconate_sink$f	−1.	0	0	0	0	0

In[15]:=
```
(* Print the application of the "null space" to the "whole" matrix,
then replace values in the neighborhood of zero with zero. *)
(* By definition, all elements of the block for
 intracellular metabolites are in the neighborhood of zero. *)
Dimensions[stoichiometryMatrix.intracellularNullspaceMatrix]
MatrixForm[stoichiometryMatrix.intracellularNullspaceMatrix,
 TableHeadings → {metaboliteIds}]
MatrixForm[stoichiometryMatrix.intracellularNullspaceMatrix /.
  x_ /; (Abs[x] ≤ tolerance) → 0, TableHeadings → {metaboliteIds}]
```

Out[15]= {80, 98}

Out[16]//MatrixForm=

2dda7p_c	1.9984×10^{-15}	-4.11206×10^{-16}	2.6786×10^{-16}	7.8217×10^{-17}	−5.16358
2ddg6p_c	-1.22125×10^{-15}	1.55769×10^{-15}	-4.09496×10^{-16}	1.06699×10^{-15}	−5.20446
2dhglcn_c	-5.18696×10^{-16}	-1.87398×10^{-16}	-3.65368×10^{-16}	6.26584×10^{-17}	−2.16686
34dhbz_c	-1.11022×10^{-16}	-1.08677×10^{-15}	7.8208×10^{-16}	8.37876×10^{-16}	−8.4968
3dhq_c	0.	-5.1384×10^{-17}	-9.84386×10^{-17}	-3.93248×10^{-17}	−2.56873
3dhsk_c	0.	2.20899×10^{-16}	-1.54999×10^{-16}	-6.00843×10^{-17}	3.7753
3pg_c	6.56802×10^{-17}	-9.77234×10^{-16}	4.15646×10^{-16}	-1.97016×10^{-19}	3.50899
6p2dhglcn_c	6.5236×10^{-16}	-2.12981×10^{-16}	3.28551×10^{-16}	-9.37632×10^{-17}	4.67058
6pgc_c	1.22125×10^{-15}	1.08812×10^{-16}	2.79236×10^{-16}	-7.35375×10^{-16}	−8.85166
ac_c	-7.51485×10^{-17}	3.3709×10^{-16}	-1.80935×10^{-16}	-2.22045×10^{-16}	1.91545
acald_c	7.67209×10^{-16}	0.	-7.77156×10^{-16}	-5.51852×10^{-16}	2.12045
accoa_c	-2.24927×10^{-15}	2.06614×10^{-15}	-1.08166×10^{-15}	1.11022×10^{-15}	−1.07796
acon_c	-2.49228×10^{-16}	-6.57715×10^{-16}	6.6446×10^{-16}	2.35949×10^{-16}	−1.11022
actp_c	-5.26283×10^{-16}	1.54303×10^{-16}	3.04506×10^{-16}	6.66134×10^{-16}	−1.36453
adp_c	-1.22125×10^{-15}	2.13996×10^{-14}	-1.30624×10^{-14}	-1.66533×10^{-15}	1.70981
akg_c	-6.66134×10^{-16}	0.	-2.22045×10^{-16}	-4.84286×10^{-16}	−1.9984
amp_c	-2.05662×10^{-16}	-1.24449×10^{-15}	3.34072×10^{-16}	-5.42262×10^{-16}	−4.15022
atp_c	1.44329×10^{-15}	-2.01551×10^{-14}	1.27284×10^{-14}	2.10942×10^{-15}	−1.66541
catechol_c	3.33067×10^{-16}	6.95499×10^{-16}	-7.68698×10^{-16}	-5.40677×10^{-16}	1.55725
ccmuac_c	-3.33067×10^{-16}	1.02776×10^{-16}	4.2365×10^{-16}	5.45329×10^{-16}	−1.43541
cit_c	-1.65232×10^{-16}	1.62972×10^{-16}	-3.64328×10^{-16}	-2.29411×10^{-16}	2.22045
co2_c	-3.55271×10^{-15}	4.49792×10^{-15}	-2.27357×10^{-15}	1.01076×10^{-15}	−2.19239
coa_c	2.24927×10^{-15}	-2.06614×10^{-15}	1.08166×10^{-15}	-1.11022×10^{-15}	1.07796
dhap_c	-1.65942×10^{-15}	2.12708×10^{-15}	-9.92501×10^{-16}	4.15736×10^{-16}	−1.47519
e4p_c	-1.44329×10^{-15}	5.64058×10^{-16}	-2.77219×10^{-16}	-4.82228×10^{-16}	1.36935
etoh_c	-2.75392×10^{-16}	0.	3.33067×10^{-16}	8.28166×10^{-16}	−6.88041
f6p_c	-8.88178×10^{-16}	-9.05573×10^{-16}	2.55881×10^{-16}	6.54574×10^{-16}	4.32663
fdp_c	8.30761×10^{-16}	-6.57715×10^{-16}	1.47658×10^{-16}	-7.86496×10^{-16}	−6.32302
fum_c	1.60951×10^{-15}	4.11073×10^{-16}	2.46096×10^{-16}	7.86496×10^{-17}	1.24485

fum_c	1.60051×10^{-15}	-4.11072×10^{-16}	-2.46096×10^{-16}	-7.86496×10^{-17}	1.24485
g3p_c	4.38174×10^{-16}	-1.53486×10^{-15}	3.15094×10^{-16}	-2.3974×10^{-16}	-6.29738
g6p_c	8.79931×10^{-16}	-5.42866×10^{-16}	-1.11497×10^{-16}	-3.5449×10^{-17}	2.42854
glc__D_c	-6.89416×10^{-16}	1.9616×10^{-17}	2.82043×10^{-16}	2.59081×10^{-16}	-9.91685
glcn_c	1.11863×10^{-16}	-3.52174×10^{-16}	9.68155×10^{-17}	-3.19568×10^{-16}	6.40186
gln__L_c	1.33227×10^{-15}	-1.77636×10^{-15}	5.55112×10^{-16}	-4.71897×10^{-16}	0.
glu__L_c	1.11022×10^{-16}	8.88178×10^{-16}	0.	4.96617×10^{-16}	-4.44089
glx_c	-7.77156×10^{-16}	4.44089×10^{-16}	-3.33067×10^{-16}	-4.40024×10^{-17}	2.97505
glyc3p_c	8.96662×10^{-16}	-5.70334×10^{-16}	3.54564×10^{-16}	-5.44785×10^{-16}	-1.11361
glyc_c	-5.24277×10^{-16}	7.05381×10^{-16}	-4.22114×10^{-16}	5.89322×10^{-16}	1.22893
h2o_c	-4.77396×10^{-15}	-1.82826×10^{-14}	1.14018×10^{-14}	4.10783×10^{-15}	-1.65473
h_c	-7.66054×10^{-15}	2.28361×10^{-14}	-1.26674×10^{-14}	-4.32987×10^{-15}	9.43761
hco3_c	-1.66152×10^{-16}	8.22144×10^{-17}	2.70706×10^{-16}	3.34261×10^{-16}	-6.32302
icit_c	2.88658×10^{-15}	-1.55431×10^{-15}	3.33067×10^{-16}	-6.63862×10^{-16}	1.20119
lac__D_c	9.08673×10^{-17}	-2.53594×10^{-16}	1.464×10^{-16}	6.72415×10^{-17}	-3.0875
mal__L_c	2.22045×10^{-16}	8.88178×10^{-16}	2.19813×10^{-16}	4.44089×10^{-16}	-1.33227
nad_c	3.10862×10^{-15}	-5.21805×10^{-15}	2.44156×10^{-15}	-5.55112×10^{-16}	-1.11022
nadh_c	-3.10862×10^{-15}	5.21805×10^{-15}	-2.44156×10^{-15}	5.55112×10^{-16}	1.11022
nadp_c	-1.11022×10^{-15}	6.32827×10^{-15}	-3.66052×10^{-15}	7.77156×10^{-16}	3.9968
nadph_c	1.11022×10^{-15}	-6.32827×10^{-15}	3.66052×10^{-15}	-7.77156×10^{-16}	-3.9968
nh4_c	2.22045×10^{-16}	-8.88178×10^{-16}	0.	-2.08202×10^{-16}	-6.66134
o2_c	0.	1.60959×10^{-15}	-9.74478×10^{-16}	-5.78918×10^{-16}	1.06674
oaa_c	-6.24194×10^{-16}	1.00774×10^{-15}	-3.62505×10^{-17}	8.82159×10^{-16}	-2.22045
pep_c	-6.66134×10^{-16}	-3.10756×10^{-16}	-1.62598×10^{-16}	-6.96556×10^{-16}	8.88178
pi_c	-2.10942×10^{-15}	1.91294×10^{-14}	-1.23155×10^{-14}	-3.88578×10^{-15}	1.63753
pyr_c	-4.44089×10^{-16}	-3.55271×10^{-15}	2.44249×10^{-15}	-1.33227×10^{-15}	-8.88178
q8_c	-1.1049×10^{-15}	3.63586×10^{-16}	6.1929×10^{-16}	1.02957×10^{-15}	-6.71445
q8h2_c	1.1049×10^{-15}	-3.63586×10^{-16}	-6.1929×10^{-16}	-1.02957×10^{-15}	6.71445
r5p_c	5.55112×10^{-16}	-1.17261×10^{-15}	4.17771×10^{-16}	-1.34434×10^{-16}	-1.66931
ru5p__D_c	-1.11022×10^{-16}	1.69655×10^{-15}	-6.26305×10^{-16}	4.86794×10^{-16}	-2.63944
s7p_c	-3.33067×10^{-16}	2.33192×10^{-16}	5.2225×10^{-17}	1.34611×10^{-16}	-4.92594
succ_c	4.44089×10^{-16}	-1.47225×10^{-15}	1.94289×10^{-15}	-5.55112×10^{-17}	7.21645
xu5p__D_c	4.44089×10^{-16}	-4.47098×10^{-17}	1.66808×10^{-16}	-1.69908×10^{-16}	6.195
ac_e	7.51485×10^{-17}	-3.3709×10^{-16}	1.80935×10^{-16}	1.	-1.91545
acald_e	0.	0.	1.	0.	0.
akg_e	0.	0.	0.	0.	0.
co2_e	0.	0.	0.	0.	0.
fum_e	-1.60051×10^{-15}	4.11072×10^{-16}	2.46096×10^{-16}	7.86496×10^{-17}	-1.24485
glc__D_e	0.	0.	0.	0.	0.
gln__L_e	0.	0.	0.	0.	0.
glu__L_e	1.	-2.	1.	3.33755×10^{-15}	-1
glyc_e	-3.72385×10^{-16}	-1.35047×10^{-16}	6.75507×10^{-17}	-4.45367×10^{-17}	-1.15314
h2o_e	0.5	4	2	1	2.56641

h2o_c	0.5	−4.	2.	−1.	−2.5
h_e	−4.	2.	−1.	1.	−1
lac__D_e	0.	0.	0.	0.	0.
mal__L_e	−2.5	3.	−1.	1.	−1
nh4_e	−1.	2.	−1.	-2.68217×10^{-15}	1.
o2_e	1.	-1.77996×10^{-15}	8.3286×10^{-16}	8.16033×10^{-16}	1.83575
pi_e	−1.	5.94371×10^{-16}	-8.07814×10^{-16}	2.35488×10^{-15}	1.30489
pyr_e	3.	−4.	1.	−2.	3.
succ_e	−1.	2.	−1.	-2.38698×10^{-15}	1.66533
toh_e	-4.91817×10^{-16}	1.	−1.	-2.76314×10^{-16}	4.75996

Out[17]//MatrixForm=

2dda7p_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2ddg6p_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2dhglcn_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34dhbz_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3dhq_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3dhsk_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3pg_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6p2dhglcn_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6pgc_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ac_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
acald_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
accoa_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
acon_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
actp_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
adp_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
akg_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
amp_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
atp_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
catechol_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ccmuac_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
cit_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
co2_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
coa_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dhap_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e4p_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
etoh_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
f6p_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
fdp_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
fum_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g3p_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g6p_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
glc__D_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
glcn_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
gln__L_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
glu__L_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
glx_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
glyc3p_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
glyc_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

h2o_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
h_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
hco3_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
icit_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
lac__D_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
mal__L_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
nad_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
nadh_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
nadp_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
nadph_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
nh4_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
o2_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
oaa_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
pep_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
pi_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
pyr_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
q8_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
q8h2_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
r5p_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ru5p__D_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
s7p_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
succ_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
xu5p__D_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ac_e	0	0	0	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
acald_e	0	0	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
akg_e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
co2_e	0	0	0	0	0	0	0	1.	0	0	0	0	1.	0	0	0	0	0	0	
fum_e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
glc__D_e	0	0	0	0	0	0	0	0	0	0	0	0	0	1.	0	0	0	0	0	
gln__L_e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
glu__L_e	1.	−2.	1.	0	−1.	0	0	1.	0	0	−1.	0	0	0	0	0	0	0	0	
glyc_e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
h2o_e	0.5	−4.	2.	−1.	0	0	0	2.	0	0	−1.	0	0	0	1.	0	0	0	0	0
h_e	−4.	2.	−1.	1.	−1.	0	0	−2.	0	0	−1.	0	0	0	0	1.	0	0	0	
lac__D_e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
mal__L_e	−2.5	3.	−1.	1.	−1.	0	0	0	−2.	0	0	1.	0	0	0	0	0	0	0	0	−
nh4_e	−1.	2.	−1.	0	1.	0	0	0	−1.	0	0	1.	0	0	0	0	0	1.	0	0
o2_e	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.	0
pi_e	−1.	0	0	0	0	0	0	0	0	0	0	−1.	0	0	0	0	0	0	0	1.
pyr_e	3.	−4.	1.	−2.	3.	0	0	0	2.	0	0	−3.	0	0	0	0	0	0	0	0
succ_e	−1.	2.	−1.	0	0	0	0	0	−1.	0	0	1.	0	0	0	0	0	0	0	0
toh_e	0	1.	−1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

In[18]:=
```
Dimensions[extracellularStoichiometryMatrix.intracellularNullspaceMatrix]
MatrixForm[extracellularStoichiometryMatrix.intracellularNullspaceMatrix,
 TableHeadings → {extracellularMetaboliteIds}]
MatrixForm[extracellularStoichiometryMatrix.intracellularNullspaceMatrix /.
  x_ /; (Abs[x] ≤ tolerance) → 0, TableHeadings → {extracellularMetaboliteIds}]
```

Out[18]= {19, 98}

Out[19]//MatrixForm=

ac_e	7.51485×10^{-17}	-3.3709×10^{-16}	1.80935×10^{-16}	1.	-1.91545×1
acald_e	0.	0.	1.	0.	0.
akg_e	0.	0.	0.	0.	0.
co2_e	0.	0.	0.	0.	0.
fum_e	-1.60051×10^{-15}	4.11072×10^{-16}	2.46096×10^{-16}	7.86496×10^{-17}	-1.24485×1
glc__D_e	0.	0.	0.	0.	0.
gln__L_e	0.	0.	0.	0.	0.
glu__L_e	1.	−2.	1.	3.33755×10^{-15}	−1.
glyc_e	-3.72385×10^{-16}	-1.35047×10^{-16}	6.75507×10^{-17}	-4.45367×10^{-17}	-1.15314×1
h2o_e	0.5	−4.	2.	−1.	-2.56643×1
h_e	−4.	2.	−1.	1.	−1.
lac__D_e	0.	0.	0.	0.	0.
mal__L_e	−2.5	3.	−1.	1.	−1.
nh4_e	−1.	2.	−1.	-2.68217×10^{-15}	1.
o2_e	1.	-1.77996×10^{-15}	8.3286×10^{-16}	8.16033×10^{-16}	1.83575×1
pi_e	−1.	5.94371×10^{-16}	-8.07814×10^{-16}	2.35488×10^{-15}	1.30489×1
pyr_e	3.	−4.	1.	−2.	3.
succ_e	−1.	2.	−1.	-2.38698×10^{-15}	1.66533×1
toh_e	-4.91817×10^{-16}	1.	−1.	-2.76314×10^{-16}	4.75996×1

Out[20]//MatrixForm=

ac_e	0	0	0	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
acald_e	0	0	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
akg_e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
co2_e	0	0	0	0	0	0	0	0	1.	0	0	0	0	1.	0	0	0	0	0	0	0
fum_e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
glc__D_e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.	0	0	0	0	0	0
gln__L_e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
glu__L_e	1.	−2.	1.	0	−1.	0	0	0	1.	0	0	−1.	0	0	0	0	0	0	0	0	0
glyc_e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
h2o_e	0.5	−4.	2.	−1.	0	0	0	0	2.	0	0	−1.	0	0	0	1.	0	0	0	0	0.5
h_e	−4.	2.	−1.	1.	−1.	0	0	0	−2.	0	0	−1.	0	0	0	0	1.	0	0	0	1.
lac__D_e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
mal__L_e	−2.5	3.	−1.	1.	−1.	0	0	0	−2.	0	0	1.	0	0	0	0	0	0	0	0	−1.5
nh4_e	−1.	2.	−1.	0	1.	0	0	0	−1.	0	0	1.	0	0	0	0	0	1.	0	0	0
o2_e	1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.	0	0
pi_e	−1.	0	0	0	0	0	0	0	0	0	0	−1.	0	0	0	0	0	0	0	1.	1.
pyr_e	3.	−4.	1.	−2.	3.	0	0	0	2.	0	0	−3.	0	0	0	0	0	0	0	0	4.
succ_e	−1.	2.	−1.	0	0	0	0	0	−1.	0	0	1.	0	0	0	0	0	0	0	0	0
toh_e	0	1.	−1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0