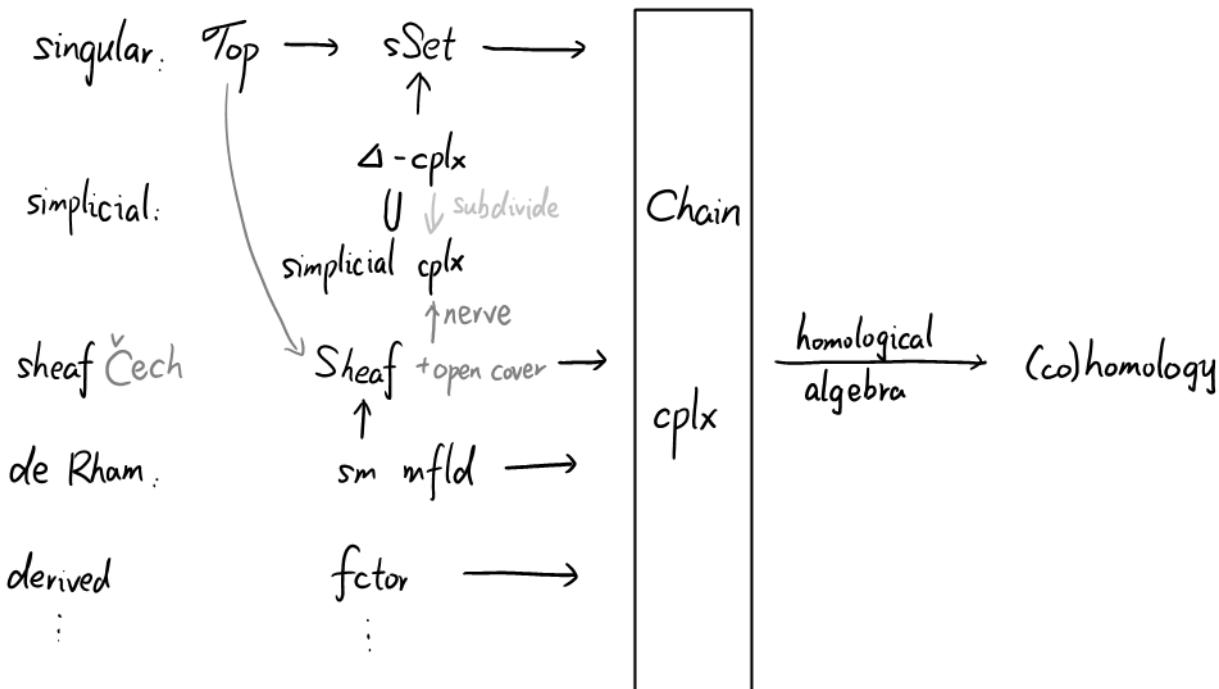


Eine Woche, ein Beispiel

6.25 (co)homology of simplicial set

<https://ncatlab.org/nlab/show/simplicial+complex>
<https://mathoverflow.net/questions/18544/sheaves-over-simplicial-sets>



Today: $\text{sSet} \longrightarrow \text{chain cplx} \dashrightarrow (\text{co})\text{homology}$

1. definition and basic examples
2. connection with simplicial complexes
3. more structures
4. connection with sheaf cohomology + derived category

1. definition and basic examples

Def. For $X \in s\text{Set}$, $G \in \text{Mod}(\mathbb{Z})$, define

We use Δ here because
we are considering $X = \Delta^n$ case.
May change to x in the future.

$$C_n(X; G) = \bigoplus_{x \in X_n} G \quad 0 \leftarrow \bigoplus_{x \in X_0} G \xleftarrow{(d'_0 - d'_1)^*} \bigoplus_{x \in X_1} G \xleftarrow{(d'_0 - d'_1 + d'_2)^*} \bigoplus_{x \in X_2} G \dots$$

$$C^n(X; G) = \prod_{x \in X_n} G \quad 0 \longrightarrow \prod_{x \in X_0} G \xrightarrow{\text{dual}} \prod_{x \in X_1} G \longrightarrow \prod_{x \in X_2} G \dots$$

$$C_n^{BM}(X; G) =$$

$$C_c^n(X; G) =$$

$$\text{Hom}_{\mathbb{Z}\text{-mod}}\left(\bigoplus_{x \in X_n} \mathbb{Z}, G\right) \cong \prod_{x \in X_n} \text{Hom}_{\mathbb{Z}\text{-mod}}(\mathbb{Z}, G) \cong \prod_{x \in X_n} G$$

<https://math.stackexchange.com/questions/102725/calculating-the-cohomology-with-compact-support-of-the-open-m%C3%b6bius-strip?rq=1>
<https://math.stackexchange.com/questions/3215960/cohomology-with-compact-supports-of-infinite-trivalent-tree>

Rmk. Prof. Scholze told me that we cannot define

Borel-Moore homology or cpt supported cohomology, not to say six factors for sset.
If there were any sheaf on sset, it should behave like perverse sheaf.

E.g. 1 For $A \in \text{Top}$ discrete, $X := \mathcal{S}(A) \in \text{Set}$, one can compute

$$\text{wished} \left\{ \begin{array}{l} C(X; G) : 0 \xleftarrow{\oplus_{a \in A} G} \xleftarrow{o} \oplus_{a \in A} G \xleftarrow{\text{Id}} \oplus_{a \in A} G \xleftarrow{o} \oplus_{a \in A} G \xleftarrow{\text{Id}} \dots \\ C^*(X; G) : 0 \rightarrow \prod_{a \in A} G \xrightarrow{o} \prod_{a \in A} G \xrightarrow{\text{Id}} \prod_{a \in A} G \xleftarrow{o} \prod_{a \in A} G \xrightarrow{\text{Id}} \dots \\ C_c^{\text{BM}}(X; G) : 0 \leftarrow \prod_{a \in A} G \xleftarrow{o} \prod_{a \in A} G \xrightarrow{\text{Id}} \prod_{a \in A} G \xleftarrow{o} \prod_{a \in A} G \xleftarrow{\text{Id}} \dots \\ C_c(X; G) : 0 \rightarrow \bigoplus_{a \in A} G \xrightarrow{o} \bigoplus_{a \in A} G \xrightarrow{\text{Id}} \bigoplus_{a \in A} G \xrightarrow{o} \bigoplus_{a \in A} G \xrightarrow{\text{Id}} \dots \end{array} \right.$$

Therefore,

$$H_n(X; G) = \begin{cases} \bigoplus_{a \in A} G & n=0 \\ 0 & n>0 \end{cases}$$

$$H^n(X; G) = \begin{cases} \prod_{a \in A} G & n=0 \\ 0 & n>0 \end{cases}$$

$$H_n^{\text{BM}}(X; G) = \begin{cases} \prod_{a \in A} G & n=0 \\ 0 & n>0 \end{cases}$$

$$H_c^n(X; G) = \begin{cases} \bigoplus_{a \in A} G & n=0 \\ 0 & n>0 \end{cases}$$

Eg. 2. We want to compute $H_n(\Delta'; G)$ & $H^n(\Delta'; G)$.

Notice that $\#\Delta'_k = k+2$, so

$$C(\Delta'; G) : 0 \xleftarrow{G^{\oplus 2} \begin{pmatrix} 0 & 1 & 0 \\ 0 & -1 & 0 \end{pmatrix}} G^{\oplus 3} \xleftarrow{G^{\oplus 4} \begin{pmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}} G^{\oplus 5} \xleftarrow{G^{\oplus 6} \begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 & 0 \end{pmatrix}} G^{\oplus 7} \dots$$

basis: $d_0' \triangleq x_0 \xrightarrow{\quad}$; $x_0 \xrightarrow{\quad}$

remember indexes: $d_1' \triangleq x_1 \xrightarrow{\quad}$; $x_1 \xrightarrow{\quad}$

$x_2 \xrightarrow{\quad}$; $x_2 \xrightarrow{\quad}$

$x_3 \xrightarrow{\quad}$; $x_3 \xrightarrow{\quad}$

$x_4 \xrightarrow{\quad}$; $x_4 \xrightarrow{\quad}$

$0 = x_0 - x_0 \xleftarrow{\quad} x_0$; $0 = x_0 - x_0 + x_0 - x_0 \xleftarrow{\quad} x_0$

$x_0 - x_1 = x_0 - x_1 \xleftarrow{\quad} x_1$; $x_0 - x_1 = x_0 - x_1 + x_1 - x_1 \xleftarrow{\quad} x_1$

$0 = x_1 - x_1 \xleftarrow{\quad} x_2$; $0 = x_1 - x_1 + x_2 - x_2 \xleftarrow{\quad} x_2$

$x_2 - x_3 = x_2 - x_2 + x_2 - x_3 \xleftarrow{\quad} x_3$

$0 = x_3 - x_3 + x_3 - x_3 \xleftarrow{\quad} x_4$

$x_0 = x_0 - x_0 + x_0 \xleftarrow{\quad} x_0$

$x_0 = x_0 - x_1 + x_1 \xleftarrow{\quad} x_1$

$x_2 = x_1 - x_1 + x_2 \xleftarrow{\quad} x_2$

$x_2 = x_2 - x_2 + x_2 \xleftarrow{\quad} x_3$

By taking the transpose, one get

$$C'(\Delta'; G) : 0 \rightarrow G^{\oplus 2} \xrightarrow{\begin{pmatrix} 0 & 0 \\ 1 & -1 \end{pmatrix}} G^{\oplus 3} \xrightarrow{\begin{pmatrix} 1 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \end{pmatrix}} G^{\oplus 4} \xrightarrow{\begin{pmatrix} 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 \\ 0 & 0 & 0 & 0 \end{pmatrix}} G^{\oplus 5} \dots$$

Therefore,

$$H_n(\Delta'; G) = \begin{cases} G & n=0 \\ 0 & n>0 \end{cases}$$

$$H^n(\Delta'; G) = \begin{cases} G & n=0 \\ 0 & n>0 \end{cases}$$

Rmk. Actually, we have chain homotopy equivalence between $C_*(\Delta'; G)$ and $C_*(\Delta^o; G)$.

$$\begin{array}{c}
 \Delta' C_*(\Delta'; G) : 0 \leftarrow G^{\oplus 2} \xleftarrow{\begin{pmatrix} 0 & 1 & 0 \\ 0 & -1 & 0 \end{pmatrix}} G^{\oplus 3} \xleftarrow{\begin{pmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{pmatrix}} G^{\oplus 4} \xleftarrow{\begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 & 0 \end{pmatrix}} G^{\oplus 5} \dots \\
 \downarrow s'_* \qquad \downarrow (11) \qquad \downarrow (111) \qquad \downarrow (1111) \qquad \downarrow (11111) \\
 \Delta^o C_*(\Delta^o; G) : 0 \leftarrow G \xleftarrow{o} G \xleftarrow{Id} G \xleftarrow{o} G \dots \\
 \Delta^o C_*(\Delta^o; G) : 0 \leftarrow G \xleftarrow{o} G \xleftarrow{Id} G \xleftarrow{o} G \dots \\
 \downarrow d'_* \qquad \downarrow (10) \qquad \downarrow (10) \qquad \downarrow (10) \qquad \downarrow (10) \\
 \Delta' C_*(\Delta'; G) : 0 \leftarrow G^{\oplus 2} \xleftarrow{\begin{pmatrix} 0 & 1 & 0 \\ 0 & -1 & 0 \end{pmatrix}} G^{\oplus 3} \xleftarrow{\begin{pmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{pmatrix}} G^{\oplus 4} \xleftarrow{\begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 & 0 \end{pmatrix}} G^{\oplus 5} \dots \\
 \downarrow s'_* \qquad \downarrow d'_* \qquad \downarrow (10) \qquad \downarrow (10) \qquad \downarrow (10)
 \end{array}$$

$$\text{s.t. } s'_* \circ d'_* = Id_{C_*(\Delta'; G)}, \quad d'_* \circ s'_* \sim Id_{C_*(\Delta^o; G)}.$$

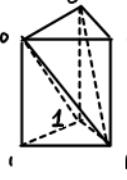
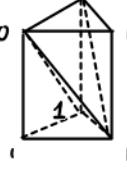
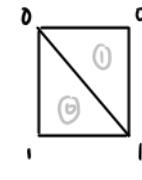
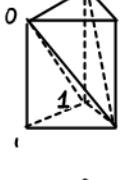
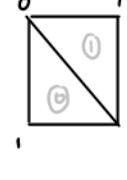
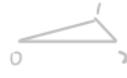
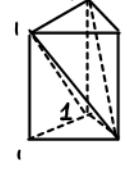
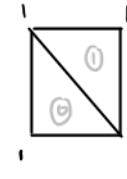
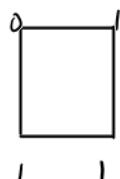
In fact, we have

$$\begin{array}{c}
 C_*(\Delta'; G) : 0 \leftarrow G^{\oplus 2} \xleftarrow{\begin{pmatrix} 0 & 1 & 0 \\ 0 & -1 & 0 \end{pmatrix}} G^{\oplus 3} \xleftarrow{\begin{pmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{pmatrix}} G^{\oplus 4} \xleftarrow{\begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 & 0 \end{pmatrix}} G^{\oplus 5} \dots \\
 \downarrow Id \qquad \downarrow (10)_* \qquad \downarrow (10) \\
 C_*(\Delta^o; G) : 0 \leftarrow G^{\oplus 2} \xleftarrow{\begin{pmatrix} 0 & 1 & 0 \\ 0 & -1 & 0 \end{pmatrix}} G^{\oplus 3} \xleftarrow{\begin{pmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{pmatrix}} G^{\oplus 4} \xleftarrow{\begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 & 0 \end{pmatrix}} G^{\oplus 5} \dots
 \end{array}$$

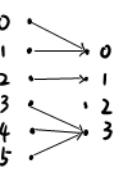
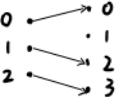
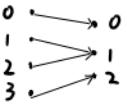
$$\begin{array}{ccc}
 x_0 & \xrightarrow{\quad} & x_0 \\
 x_1 & \xrightarrow{\quad} & x_0 \\
 & \searrow & \nearrow \\
 & x_1 &
 \end{array}$$

$$\begin{array}{c}
 x_0 \xrightarrow{\quad} x_0 - x_0 + x_0 = x_0 \\
 x_1 \xrightarrow{\quad} x_1 - x_1 + x_1 = x_1 \\
 x_2 \xrightarrow{\quad} x_1 - x_2 + x_2 = x_1 \\
 x_3 \xrightarrow{\quad} x_1 - x_2 + x_3 \\
 \\
 x_0 \xrightarrow{\quad} x_0 - x_0 = 0 \\
 x_1 \xrightarrow{\quad} x_1 - x_1 = 0 \\
 x_2 \xrightarrow{\quad} x_1 - x_2
 \end{array}$$

Ex. Observe the picture, try to translate the calculation in geometrical language.



E.g. 3. When we want to compute $H_n(\Delta^m; G)$ and $H^n(\Delta^m; G)$, we'd better to give elements in $\Delta_n^m \approx \{\text{basis of } C_n(\Delta^m; G)\}$ a better notation.
 The following table shows some typical element in
 $C_n(\Delta^m; G) = \langle \alpha : [n] \rightarrow [m] \rangle_{\alpha \in \Delta_n^m}.$

element	picture	list	count	degenerate degree
$\alpha : [5] \rightarrow [3]$ $0 \mapsto 0$ $1 \mapsto 0$ $2 \mapsto 1$ $3 \mapsto 3$ $4 \mapsto 3$ $5 \mapsto 3$		(0,0,1,3,3,3)	[2,1,0,3]	$\Delta_5^{3,43}$
$d^3 : [2] \rightarrow [3]$ $0 \mapsto 0$ $1 \mapsto 2$ $2 \mapsto 3$		(0,2,3)	[1,0,1,1]	$\Delta_2^{3,4}$
$s_1^3 : [3] \rightarrow [2]$ $0 \mapsto 0$ $1 \mapsto 1$ $2 \mapsto 1$ $3 \mapsto 2$		(0,1,1,2)	[1,2,1]	$\Delta_3^{2,41}$
∂_2	—	(0,0,3,3,3) -(0,0,1,3,3)	[2,0,0,3] -[2,1,0,2]	$\Delta_4^{3,43}$ $\Delta_4^{3,42}$

e.g. $\partial[2,5,3,4,1,6,0]$
 $= [2,4,3,4,1,6,0] - [2,5,2,4,1,6,0] + [2,5,3,4,0,6,0]$

2. connection with simplicial complexes.

Continuation of Eq. 2.

Even more, we have chain homotopy between $C_*(\Delta'; G)$ and $C_*(\Delta'; G)^\diamond$.

$$C_*(\Delta'; G) : 0 \leftarrow G^{\oplus 2} \xleftarrow{\begin{pmatrix} 0 & 1 & 0 \\ 0 & -1 & 0 \end{pmatrix}} G^{\oplus 3} \xleftarrow{\begin{pmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}} G^{\oplus 4} \xleftarrow{\begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 & 0 \end{pmatrix}} G^{\oplus 5} \dots$$

$$\downarrow \text{projection} \quad \downarrow \text{Id} \quad \downarrow (111) \quad \downarrow 0 \quad \downarrow 0$$

$$C_*(\Delta'; G)^\diamond : 0 \leftarrow G^{\oplus 2} \xleftarrow{\begin{pmatrix} 1 \\ -1 \end{pmatrix}} G \xleftarrow{0} 0 \leftarrow 0 \leftarrow 0 \dots$$

$$C_*(\Delta'; G)^\diamond : 0 \leftarrow G^{\oplus 2} \xleftarrow{\begin{pmatrix} 1 \\ -1 \end{pmatrix}} G \xleftarrow{0} 0 \leftarrow 0 \leftarrow 0 \dots$$

$$\downarrow \text{inclusion} \quad \downarrow \text{Id} \quad \downarrow \begin{pmatrix} 0 \\ 0 \end{pmatrix} \quad \downarrow 0 \quad \downarrow 0$$

$$C_*(\Delta'; G) : 0 \leftarrow G^{\oplus 2} \xleftarrow{\begin{pmatrix} 0 & 1 & 0 \\ 0 & -1 & 0 \end{pmatrix}} G^{\oplus 3} \xleftarrow{\begin{pmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}} G^{\oplus 4} \xleftarrow{\begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 & 0 \end{pmatrix}} G^{\oplus 5} \dots$$

In fact, we have

$$C_*(\Delta'; G) : 0 \leftarrow G^{\oplus 2} \xleftarrow{\begin{pmatrix} 0 & 1 & 0 \\ 0 & -1 & 0 \end{pmatrix}} G^{\oplus 3} \xleftarrow{\begin{pmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}} G^{\oplus 4} \xleftarrow{\begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 & 0 \end{pmatrix}} G^{\oplus 5} \dots$$

$$\downarrow \text{Id} \quad \downarrow \text{Id} \quad \downarrow \text{Id} \quad \downarrow \text{Id} \quad \downarrow \text{Id}$$

$$C_*(\Delta'; G)^\diamond : 0 \leftarrow G^{\oplus 2} \xleftarrow{\begin{pmatrix} 0 & 1 & 0 \\ 0 & -1 & 0 \end{pmatrix}} G^{\oplus 3} \xleftarrow{\begin{pmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}} G^{\oplus 4} \xleftarrow{\begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 & 0 \end{pmatrix}} G^{\oplus 5} \dots$$

Q: How could one find the homotopy in the general case?

Def (Stratification by skeletons)

For $X \in \text{Set}$, define

\triangleleft : non-degenerate

\triangleleft : degenerate

$$\begin{aligned} X_k^\triangleleft &= \{x \in X_k \mid x \text{ non-degenerate}\} & = X_k - (sk^{k-1}X)_k \\ X_k^\triangleleft &= \{x \in X_k \mid x \text{ degenerate}\} & = (sk^{k-1}X)_k \\ X_k^{\triangleleft i} &= \left\{ x \in X_k \mid \begin{array}{l} x = \varphi^*(y) \text{ for some } y \in X_{k-i}^\triangleleft \\ \varphi: [k-i] \rightarrow [k] \end{array} \right\} & = (sk^{k-i}X)_k - (sk^{k-i-1}X)_k \end{aligned}$$

$$0 = (sk^{-1}X)_k \subset \underbrace{(sk^0X)_k \subset (sk^1X)_k \subset \dots \subset (sk^{k-1}X)_k}_{X_k^\triangleleft} \subset (sk^kX) = X_k$$

Def. For $X \in \text{Set}$, $G \in \text{Abel}$, define the chain cplx

$$\begin{aligned} C_n(X; G)^\triangleleft &= \bigoplus_{x \in X_n^\triangleleft} G & 0 \leftarrow \bigoplus_{x \in X_0^\triangleleft} G \xleftarrow{(d_0 - d_1)^*} \bigoplus_{x \in X_1^\triangleleft} G \xleftarrow{(d_0^+ - d_0^- + d_1^+)^*} \bigoplus_{x \in X_2^\triangleleft} G \dots \\ C_n(X; G)^\triangleleft &= \bigoplus_{x \in X_n^\triangleleft} G & 0 \leftarrow \bigoplus_{x \in X_0^\triangleleft} G \xleftarrow{(d_0 - d_1)^*} \bigoplus_{x \in X_1^\triangleleft} G \xleftarrow{(d_0^+ - d_0^- + d_1^+)^*} \bigoplus_{x \in X_2^\triangleleft} G \dots \end{aligned}$$

and $H_*(X; G)^\triangleleft$, $H_*(X; G)^\triangleleft$ as crspd homology.

By definition,

$$C_*(X; G) \cong C_*(X; G)^\triangleleft \oplus C_*(X; G)^\triangleleft$$

Claim 1. $H_*(X; G)^\triangleleft = 0$, so

$$H_*(X; G) \cong H_*(X; G)^\triangleleft. \quad (\#)$$

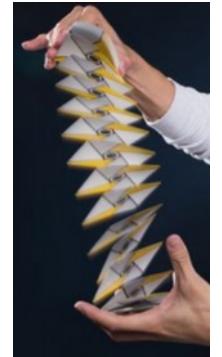
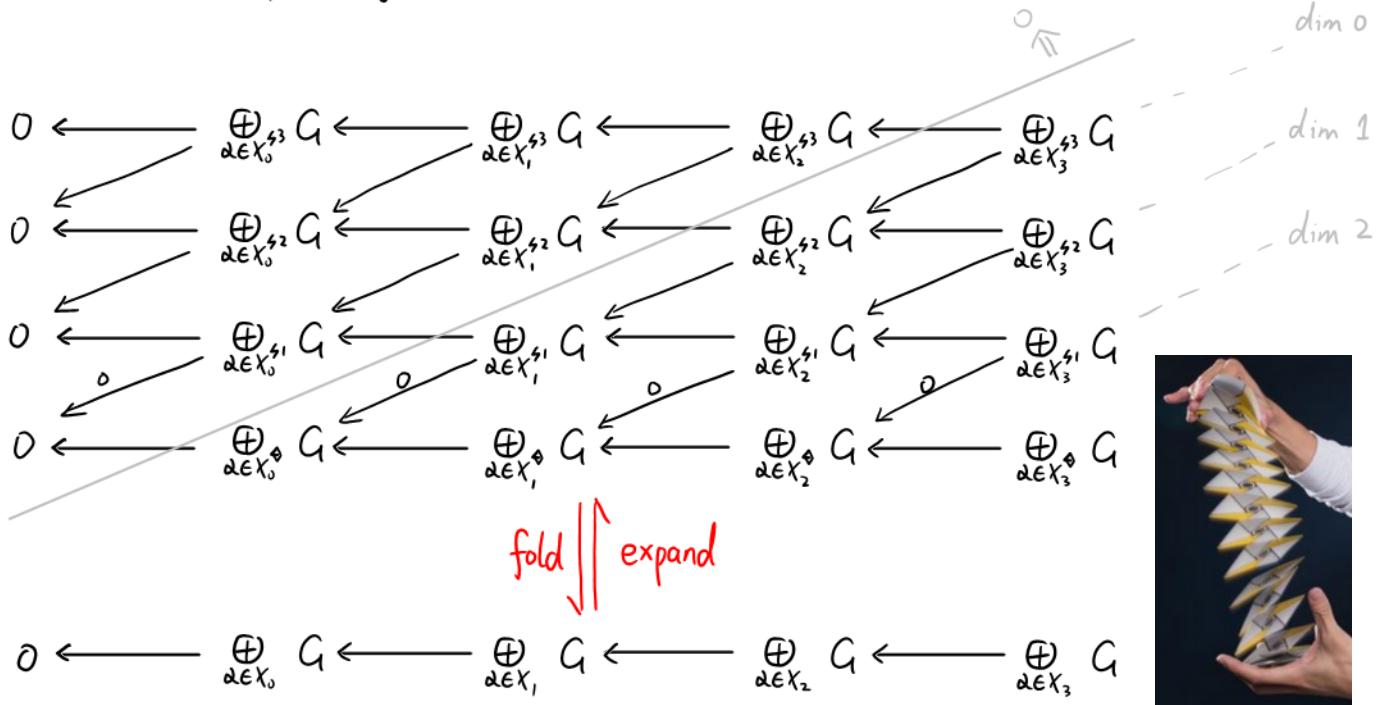
Rmk 1. Roughly, $(\#)$ says that

singular homology \approx simplicial homology.

Finally, one can compute the (co)homology of sSets without too much pain.

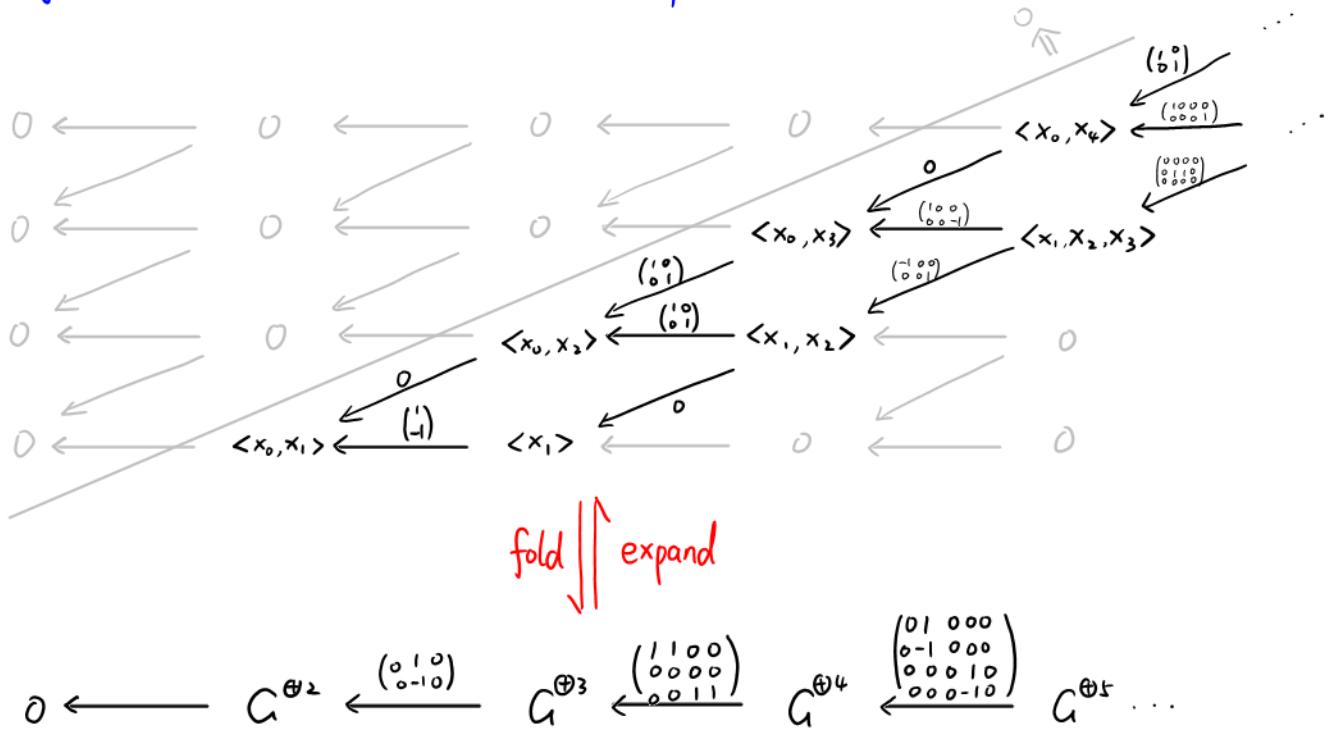
To prove Claim 1, one has to expend $C_*(X; G)$ by double complex.

Def (Double complex of $C(X, G)$) $\swarrow + \searrow = 0$



fold / expand

Eg. For $X = \Delta'$, we have double complex



Claim 2. We have chain homotopy equivalence between the following two cplx.

$$\begin{array}{ccccccc}
 0 & \longleftarrow & \bigoplus_{\alpha \in X_n^{s_0}} G & \xleftarrow{\quad 0 \quad} & \bigoplus_{\alpha \in X_{n+1}^{s_1}} G & \xleftarrow{\quad \partial' \quad} & \bigoplus_{\alpha \in X_{n+2}^{s_2}} G & \xleftarrow{\quad \partial' \quad} & \bigoplus_{\alpha \in X_{n+3}^{s_3}} G & \xleftarrow{\quad (\ast\ast) \quad} \\
 & & \parallel & & \circ \uparrow 0 & & \circ \downarrow 0 & & \circ \uparrow 0 & & \circ \downarrow 0 \\
 0 & \longleftarrow & \bigoplus_{\alpha \in X_n^{s_0}} G & \longleftarrow & 0 & \longleftarrow & 0 & \longleftarrow & 0 & \longleftarrow & 0
 \end{array}$$

i.e. $(\ast\ast)$ is exact on all terms except $\bigoplus_{\alpha \in X_n^{s_0}} G$.

Proof idea of Claim 2 for $X = \Delta^m$. (can be generalized to arbitrary X)

$$\cdots \leftarrow \bigoplus_{\alpha \in X_{n+k-1}^{s_{k-1}}} G \leftarrow \bigoplus_{\alpha \in X_{n+k}^{s_k}} G \leftarrow \bigoplus_{\alpha \in X_{n+k+1}^{s_{k+1}}} G \leftarrow \cdots$$

$\downarrow s \quad \downarrow Id \quad \downarrow s \quad \downarrow Id \quad \downarrow s \quad \downarrow Id$
 $\cdots \leftarrow \bigoplus_{\alpha \in X_{n+k-1}^{s_{k-1}}} G \leftarrow \bigoplus_{\alpha \in X_{n+k}^{s_k}} G \leftarrow \bigoplus_{\alpha \in X_{n+k+1}^{s_{k+1}}} G \leftarrow \cdots$

Define

$$s [a_1, \dots, \underbrace{a_l}_{\{0,1\}}, a_{l+1}, \dots, a_m] = \begin{cases} (-1)^i [a_1, \dots, a_l, a_{l+1}+1, \dots, a_m], & a_{k+1} \text{ even} \\ 0 & a_{k+1} \text{ odd} \end{cases}$$

$i = \sum_{j=1}^l a_j$

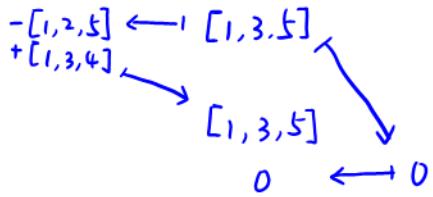
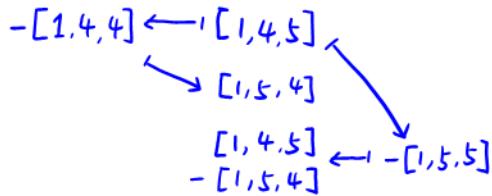
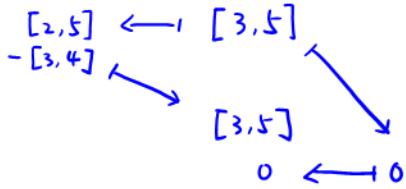
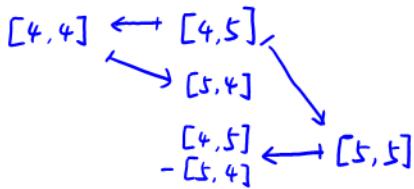
Ex. Check that s is a homotopy.

e.g. $X = \Delta^3, n=2, k=3 \Rightarrow m=3, n+k=5$

$$\begin{array}{ccccc}
 -[2,1,0,2] & \longleftrightarrow & [2,1,0,3] & & \\
 & \swarrow & \searrow & & \\
 & & -[3,1,0,2] & & \\
 & & \begin{matrix} [2,1,0,3] \\ + [3,1,0,2] \end{matrix} & & \\
 & \swarrow & \searrow & & \\
 & & [3,1,0,3] & &
 \end{array}$$

$X = \Delta^6, n=5, k=15 \Rightarrow m=6, n+k=20$

$$\begin{array}{c}
 [2,4,3,4,1,6,0] \leftarrow [2,5,3,4,1,6,0] \\
 -[2,5,2,4,1,6,0] \swarrow \quad \nearrow \\
 [3,4,3,4,1,6,0] \\
 -[3,5,2,4,1,6,0] \\
 [2,5,3,4,1,6,0] \\
 -[3,4,3,4,1,6,0] \leftarrow [3,5,3,4,1,6,0] \\
 +[3,5,2,4,1,6,0]
 \end{array}$$

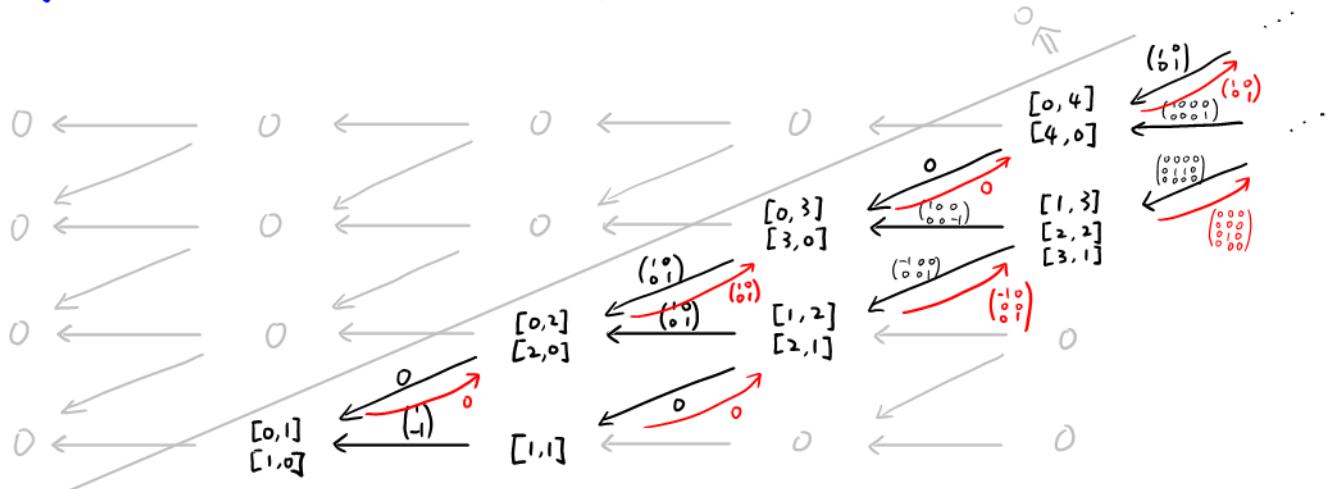


In conclusion,

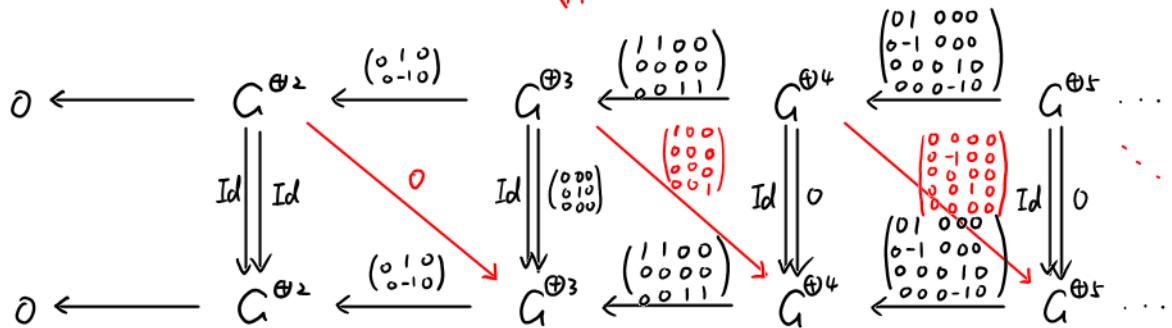
$$\text{Claim 2} \Rightarrow \text{Claim 1} \Rightarrow \text{Rmk 1}$$

Coming back to E.g. 2, one can now find a homotopy without guess.

Eg. For $X = \Delta'$, we have homotopy



fold // expand



Ex. Check that (I believe that this argument also works for general sset X)

$$\textcircled{1} \quad \begin{array}{c} \nearrow s \\ \searrow \bar{s} \end{array} + \begin{array}{c} \swarrow s \\ \nearrow \bar{s} \end{array} = 0$$

② the collected s is a homotopy.

3. more structures

math.stackexchange.com/questions/2559705/cup-product-why-do-we-need-to-consider-cohomology-with-coefficients-in-a-ring

When $G=R$ is a k -alg, the product structure on $C^*(X; R)$ is defined by

$$\begin{array}{ccc}
 & C^{i+j}(X; R) \otimes C^{i+j}(X; R) & \\
 d_{i,j,*} \otimes d'_{i,j,*} \nearrow & \downarrow & \\
 C^i(X; R) \otimes C^j(X; R) & & C^{i+j}(X; R \otimes R) \xrightarrow{\text{multiply}} C^{i+j}(X; R) \\
 f_1 \otimes f_2 \longleftarrow & & (f_1 \circ d_{i,j,*}) \otimes (f_2 \circ d'_{i,j,*}) \\
 & & f \otimes g \longmapsto fg
 \end{array}$$

the $C^*(X; R)$ -module structure on $C_*(X; G)$ is defined by

$$\begin{array}{ccc}
 & C^i(X; R) \otimes C_i(X; R) \otimes C_j(X; R) & \\
 Id \otimes d_{i,j}^*(-) \otimes d'_{i,j}^*(-) \nearrow & \downarrow & \\
 C^i(X; R) \otimes C_{i+j}(X; R) & & R \otimes C_j(X; R \otimes R) \xrightarrow{\text{multiply}} C_j(X; R) \\
 f \otimes \alpha \longleftarrow & & f(d_{i,j}^*(\alpha)) \otimes d'_{i,j}^*(\alpha) \\
 & & r \otimes \beta \longmapsto r\beta
 \end{array}$$

where $(i=3, j=2)$

$$\begin{array}{ccc}
 & \cdot \quad \cdot \quad \cdot \quad \cdot & \\
 & \searrow \quad \searrow \quad \searrow \quad \searrow & \\
 \cdot \quad \cdot \quad \cdot \quad \cdot & \cdot \quad \cdot & \\
 d_{i,j}: [i] \longrightarrow [i+j] & & d'_{i,j}: [j] \longrightarrow [i+j]
 \end{array}$$

\otimes are over k . Notice that

$$\begin{cases} C_i(X; R) = \bigoplus_{\alpha \in X_i} R \\ C^i(X; R) = \prod_{\alpha \in X_i} R \end{cases}$$

are bi R -modules.

Ex: Show that.

- $C^*(X; R)$ is a dga,
- $H^*(X; R)$ is a graded R -alg,
- $H_*(X; R)$ is a graded $H^*(X; R)$ -module.