D. Surfaces (Kirby pictures, classification, and diffeomorphisms)

we will use handlebodies to classify closed surfaces

First we have

exercise:

1) if Σ a surface and D_1, D_2 are 2 disks in Σ then
$$\overline{\Sigma - D_1} \cong \overline{\Sigma - D_2}$$
so denote $\overline{\Sigma - D_1}$ by $\widehat{\Sigma}$

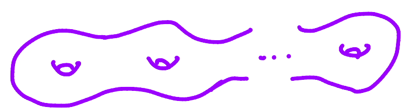
2) given Σ_1, Σ_2 the connected sum is
$$\Sigma_1 \# \Sigma_2 = \widehat{\Sigma}_1 \cup_f \widehat{\Sigma}_2 \quad \text{where } f: \partial\widehat{\Sigma}_1 \to \partial\widehat{\Sigma}_2$$
is an or$^{\underline{n}}$ rev. diffeo

show this is well-defined. ← unique up to isotopy

examples:

1) S^2  call Σ_0

2) $T^2 = S^1 \times S^1$  call Σ_1

3) $\Sigma_n = \Sigma_{n-1} \# \Sigma_1$ 

4) $P^2 = S^2/_\sim$ call N_1

ident antipodes

5) $N_n = N_{n-1} \# N_1$

Th$^{\underline{m}}$:

> any closed connected surface Σ is diffeomorphic to Σ_n or N_n for some n

we prove this by showing Σ has a handlebody decomp. that agrees with one for Σ_n or N_n

how to "see" handle decomps? Kirby pictures!

note: for surfaces F_0, F_1, we have $F_0 \cong F_1 \Leftrightarrow \widehat{F}_0 \cong \widehat{F}_1$

so given a connected surface F we can find a handle decomposition with one 0-handle and one 2-handle

and we can understand F's diffeomorphism type by considering

$$F - (2\text{-handle}) = (0\text{-handle}) \cup k\,(1\text{-handles})$$

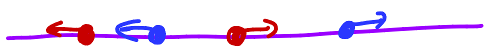
to understand this, just need to know how 1-handles are attached to $\partial(0\text{-handle}) = S^1$

i.e keep track of framed S^0's in S^1

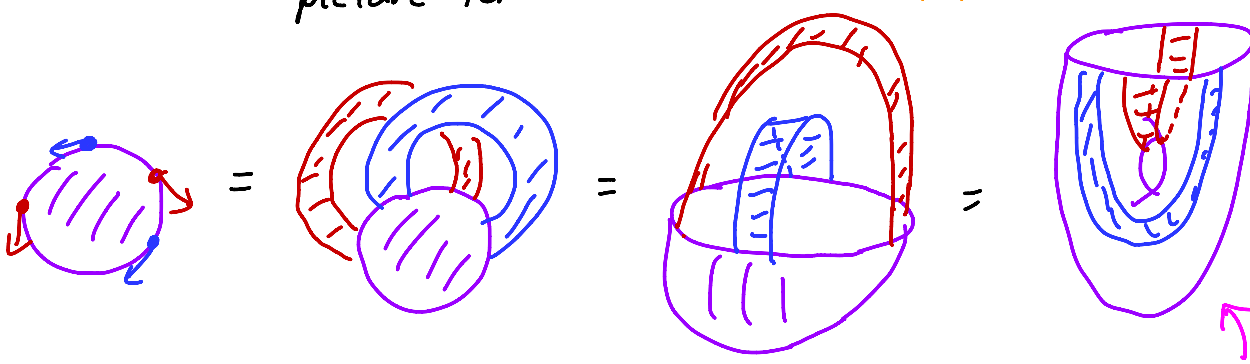
called "pointed matched circle" in bordered HF

we can assume S^0's miss some point in S^1 so think of S^0's as in $S^1 - \{pt\} \cong \mathbb{R}$

reduced studying 2-mfds to pictures in $\mathbb{R}^1$! call these "Kirby pictures"

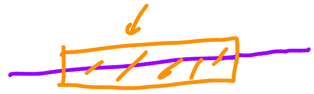
example: 1)  $\mathbb{R}$

picture for

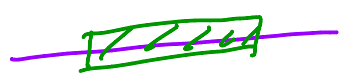


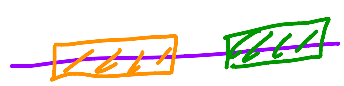
$T^2 - D^2$

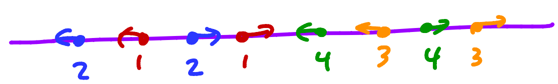
so this is a picture of T^2

2) show if F_0 has picture 

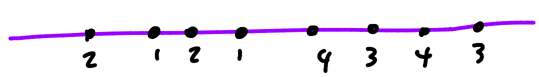
and

F_1 " "  then

$F_0 \# F_1$ " " 

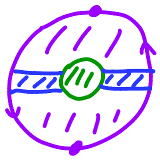
e.g Σ_2 has picture 

or



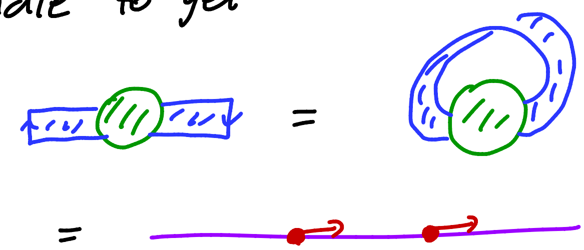
with convention, if no arrows then they point "out"

3) $P^2 =$  with pt on ∂ identified with "antipode"



note union of purple is D^2 glued to rest along S^1, i.e. a 2-handle

remove 2-handle to get



so we now have pictures of all Σ_n and N_n

We now show any F has a picture that agrees with one of these

If the picture for F has no 1-handles, then $F \cong S^2$

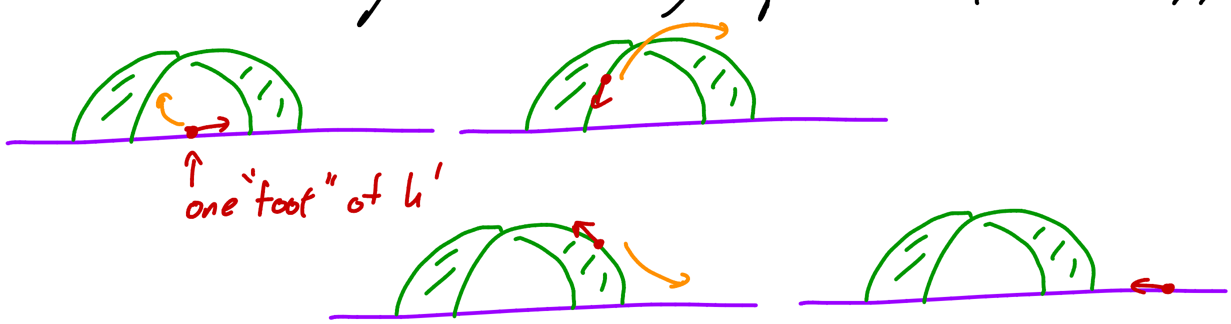
now suppose F has $k>0$ 1-handles

consider one of them: h_0^1 that is attached first

Case 1: h_0^1 not oriented

any handle h^1 attached after h_0^1 can be "slid" over h_0^1

that is recall we get the same manifold if we change the attaching map of h^1 by an isotopy

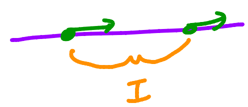


so a "handle slide" changes the picture by

exercise: Show handle slide rule is

a) can push a point into tip/tail of another handle h_0' and it comes out the tip/tail of the other "foot" of h_0'

b) if h_0' is oriented the arrow of the slid point stays same, otherwise it flips

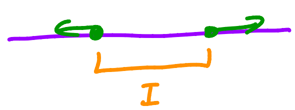
so notice any "foot" in  can be slid out of I (say to right)

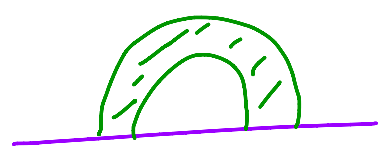
and any point to left of I can be slid to right of I by 2 handle slides

so $F =$ 

$\therefore F \cong P^2 \# F'$ F' has fewer 1-handles

Case 2: h_0' oriented





note: $\partial((0\text{-}h) \cup h_0') = S^1 \cup S^1$ not connected

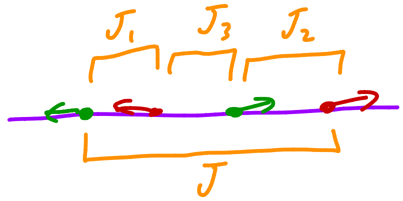
but $\partial F^0 = S^1$ connected

so must be h_1' with one foot in I and one foot out

if h_1' non oriented, then can slide to get

so now in Case 1 and $F = P^2 \# F'$ ← fewer 1-handles

if h_1' oriented, then consider interval J



note: any foot in J_1 can be slid over h_1' to get out of J
" " J_2 " " h_0' " "
" " J_3 " " h_1' to get to J_2
then over h_0' to get out of J

similarly any foot to left of J can be slid to right of J

$\therefore$ as in case 1 $F = T^2 \# F'$ with F' having fewer 1-handles

so by induction on k $F = (\#_k T^2) \# (\#_\ell P^2)$

exercise: $T^2 \# P^2 \cong P^2 \# P^2 \# P^2$

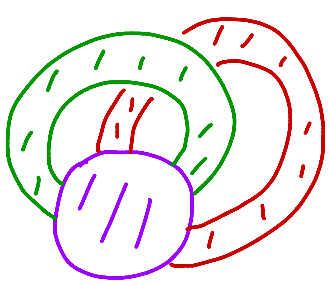
so we are done with proof of theorem!

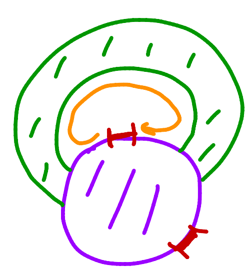
Subtle Point: Given a handlebody F and F' obtained from F by isotoping the attaching maps,

Is $F = F'$?

NO! but they are diffeomorphic!

there is a difference between "is the same as" and "diffeomorphic to"

example:  isotope attaching region of red as follows

 so it comes back to where it started

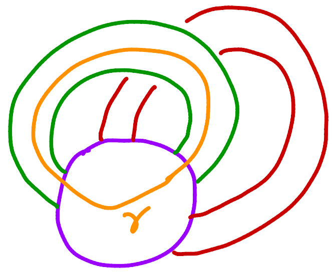
we get a family of surfaces F_t $t \in [0,1]$

with $F = F_0 = F_1$ and diffeomorphisms $\phi_t : F_0 \to F_t$

really equal!

exercise: so $f_1 : F \to F$ is a diffeomorphism of F!

1) Show f_1 is isotopic to a "Dehn twist" about γ



2) Show any diffeomorphism of an oriented surface is obtained by handle slides

(is it true for non orientable?)

E. h-cobordism theorem

the goal of this section is to prove

Th$^{\underline{m}}$ (h-cobordism theorem)

If W is an n-dimensional cobordism s.t.

1) $\pi_1(W) = \{e\} = \pi_1(\partial_\pm W)$

2) $H_*(W, \partial_- W; \mathbb{Z}) = 0$

3) $n \geq 6$

Then $W \cong \partial_- W \times [0,1]$

note: hypothesis equivalent to $\partial_\pm W \hookrightarrow W$ homotopy equivalence and $\pi_1(W) = \{e\}$

Cor:

1) Suppose $V^n \subset W$ with $\partial_- V^n = \partial_- W^n$

$$\left.\begin{array}{l} \text{a) } V^n \hookrightarrow W^n \text{ is a homotopy equivalence} \\ \text{b) } V, \partial_+ V, \partial_+ W \text{ are simply-connected} \\ \text{c) } n \geq 6 \end{array}\right\} \Rightarrow V \cong W$$

2) Suppose $M^k \subset W^n$ is a submanifold with $\partial M = \emptyset$

$$\left.\begin{array}{l} \text{a) } M \hookrightarrow W \text{ a homotopy equivalence} \\ \text{b) } M, \partial W \text{ simply-connected} \\ \text{c) } n-k \geq 3,\ n \geq 6 \end{array}\right\} \Rightarrow W \cong \text{disk bundle with zero-section } M$$