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WHAT THE PAPER SAYS · WHAT IT DOESN'T · WHY IT MATTERS

Kuda na iya rasa wari amma har yanzu ta juya ta koma wajensa. A gajimaren kama-da-wane, alkiblar da ta tuna ta taimaka

Kudan 'ya'yan itace da aka ɗaure sun rika komawa zuwa iyakar wari bayan sun shiga iska mai tsafta. Hali, modeling da perturbations na jijiyoyi suna goyon bayan karamin ƙwaƙwalwar alkibla, ba cikakkiyar taswira ba. Sakamakon ya fito ne daga gwajin virtual reality da aka sarrafa kuma bai nuna cewa ana amfani da dabara iri ɗaya a free natural flight ba.

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Kuda na iya rasa wari amma har yanzu ta juya ta koma wajensa

Kudar ta riga ta bar warin a baya.

Ta ci gaba da tafiya cikin iska mai tsafta, wani lokaci na tsawon gomman dakikoki da ɗaruruwan milimita na kama-da-wane. Daga baya sai ta juya zuwa iyakar da ta ketare, ta sake samun warin. A wannan lokacin, warin kansa ba zai iya nuna mata hanyar komawa ba.

Wannan shi ne babban abin lura a wani sabon bincike na Nature kan yadda kudan ’ya’yan itace ke kewayawa. Masu binciken suna cewa kudan sun yi amfani da ƙaramin ƙwaƙwalwar alkibla: ba taswirar dukan gajimaren wari ba, kuma ba ƙwaƙwalwar nisan da aka yi ba, sai dai tunawa da alkiblar da ke kaiwa ga wata iyaka da ba za a iya ganewa ko jin warinta a lokacin ba.

Sakamakon yana da ban sha’awa domin yana nuna cewa ƙaramin adadin bayanin da aka adana na iya isa. Amma kuma yana da sauƙin yin masa ƙarin magana fiye da abin da bayanan ke nuna. Waɗannan kudan ba su yi shawagi cikin ’yanci a wani yanayi na halitta ba. Sun yi tafiya ne yayin da aka ɗaure jikinsu a kan ƙwallon da iska ke ɗauke da ita, cikin wata duniyar kama-da-wane da aka sarrafa sosai. Binciken yana goyon bayan dabarar da ta dogara da vector a cikin wannan na’ura; ba ya nuna cewa kudan suna gina taswirar tunani, ba ya bayyana duk hanyoyin da dabbobi ke bin wari, kuma ba ya gano ƙwayoyin jijiyar da ake adana ƙwaƙwalwar a cikinsu a zahiri.

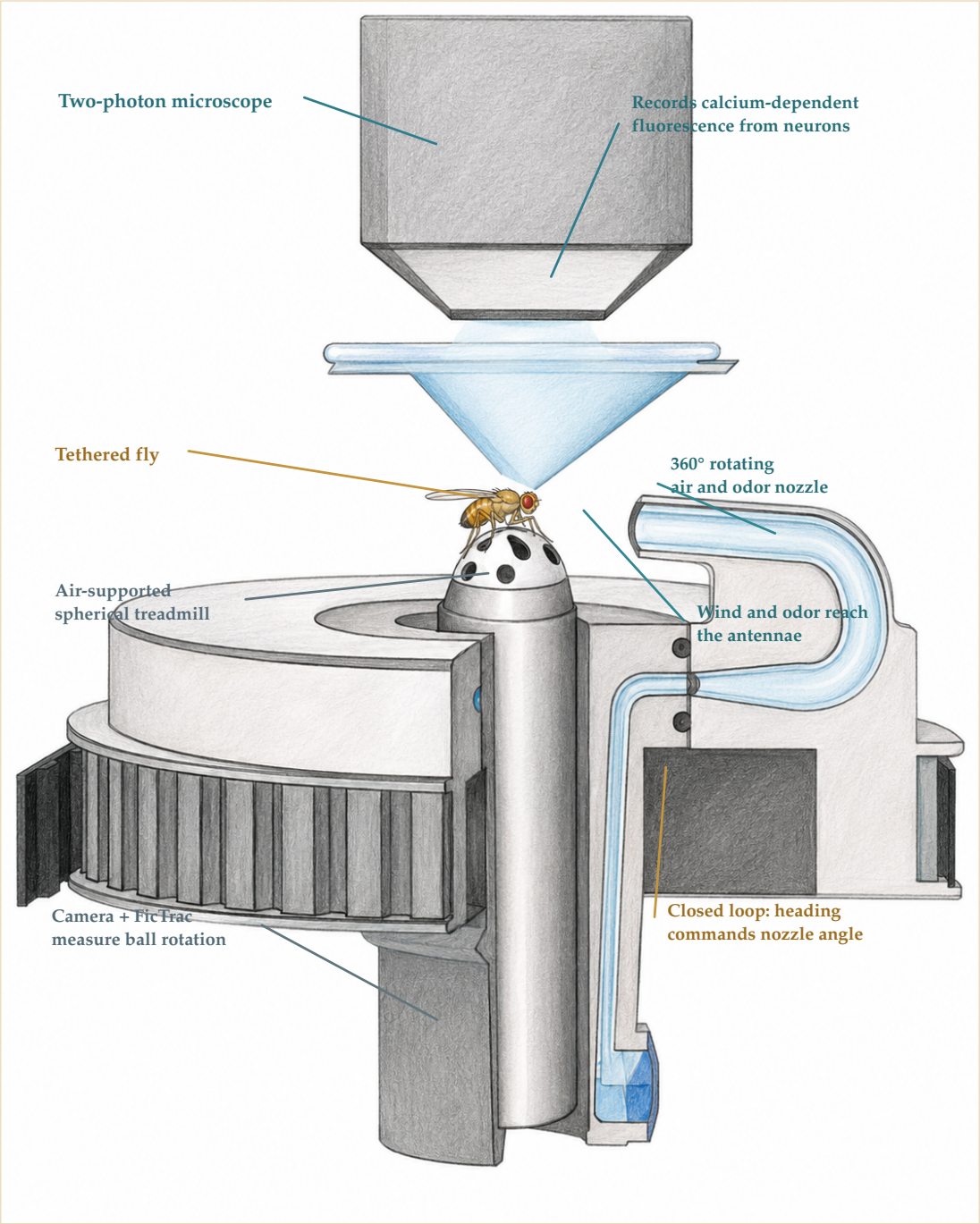
Software ne ya ƙirƙiri hanyar warin da ba a gani

Gajimaren wari shi ne yankin wari da iska ke ɗauka tana motsawa da shi. A waje, irin wannan gajimare yana karkata, yana watsewa, sannan ya sake haɗuwa yayin da iska ke sauyawa. Wannan yana sa ya yi wuya a san ainihin abin da dabba ta ji a kowane lokaci.

Masu binciken sun sa wannan matsalar ta zama mai iya sarrafawa ta hanyar **closed-loop virtual reality**. An ɗaure jikin kudar a wuri guda a saman wata ƙwallo mai nauyi kaɗan da take shawagi a kan iska. Yayin da kudar ke tafiya, kyamara tana auna juyawar ƙwallon kusan sau 60 a sakan. Software ya fassara wannan juyawa zuwa matsayi da alkibla a wani fili na kama-da-wane mai girma biyu.

Wannan alkiblar tana sarrafa bututun iska mai mota wanda zai iya juyawa digiri 360. Yayin da kudar ke sauya alkiblarta ta kama-da-wane, bututun yana motsawa a kewaye da ita don ya sa iskar ta ci gaba da zuwa daga madaidaicin alkibla a duniyar kama-da-wanen kudar. A lokaci guda, na’urorin sarrafa kwararar iska suna sauya yawan iska mai tsafta ko warin apple-cider vinegar da ke isa eriya, gwargwadon matsayin kudar na kama-da-wane. Saboda haka, ketare wata iyaka da software ya ayyana yana kunna ko kashe warin, yana ƙirƙirar wata hanya ta kama-da-wane mai faɗin milimita 50 da tsawon mita ɗaya, duk da cewa kudar ba ta taɓa barin ƙwallon ba.

Na’urar ta samar da rikodi da aka daidaita na matsayin kudar na kama-da-wane, alkiblar da take fuskanta, ko wari yana kunne ko a’a, da kuma sarrafa kwararar iska a kowane lokaci. Daga wannan rikodin, masu binciken sun sake gina hanyoyin tafiya, suka yi alama ga kowace shiga da fita, sannan suka auna yadda kudar ta koma kai tsaye. Iska ce ta ba da abin nuni na alkibla daga waje; motsin kudar kanta ne ya ƙayyade lokacin da za ta haɗu da kowace gefen iyakar warin ta kama-da-wane.



Kudar ta kasance a ɗaure a saman ƙwallon da iska ke ɗauke da ita. Kyamara da FicTrac sun juya juyawar ƙwallon zuwa motsi da alkibla ta kama-da-wane; daga nan software ta juya bututun iska-da-wari sannan ta kunna ko kashe wari gwargwadon matsayin kama-da-wane. A gwaje-gwajen hoton jijiyoyi daban, microscope na two-photon da ke saman kudar ya auna hasken fluorescence da ke dogara da calcium daga jijiyoyin EPG ko FC2, wanda ya ba da damar daidaita aikin jijiyoyi da hali. Ba a buƙaci microscope a kowane gwajin hali ba.

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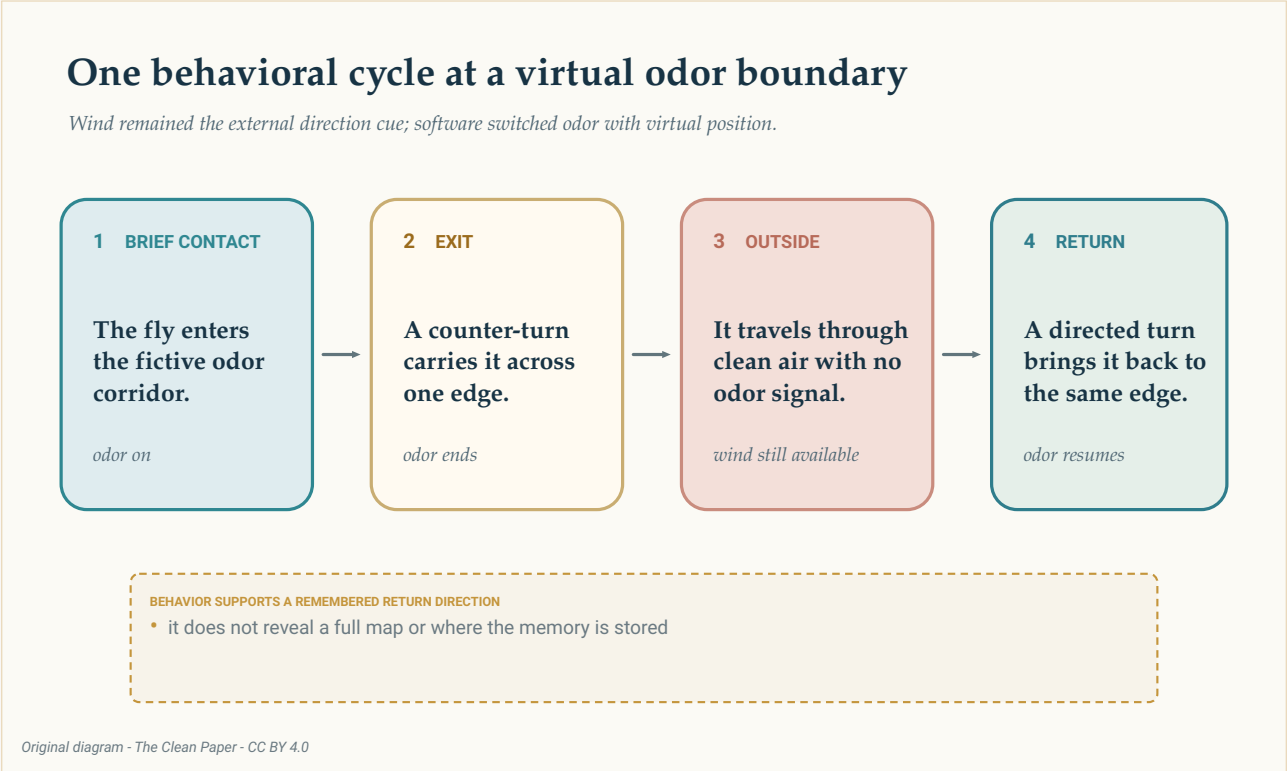

A cikin gwajin da aka sarrafa, kuda ta shiga hanyar warin ta kama-da-wane na ɗan lokaci, ta fita, ta yi tafiya cikin iska marar wari sannan ta yi komawa kai tsaye. Halin yana goyon bayan tunawa da alkiblar komawa; ba ya nuna inda aka adana wannan bayanin.

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A babban gwajin **vertical corridor**, **kuda 40** sun rika shiga warin, suna yin juyawar da ta fitar da su daga ciki, sannan suna komawa zuwa gefen da suka bari. Kalmar “vertical” ita ce sunan da takardar ta ba geometry na digiri 0: doguwar gabar hanyar ta yi layi da alkiblar zuwa sama da iska. Ba yana nufin cewa na’urar tana tsaye a tsaye ba.

Marubutan suna kiran wannan tsarin **edge tracking**, wato bibiyar gefen iyakar. **Bout** guda shi ne wani ci gaba ɗaya na hali tsakanin ketare iyaka biyu: bout na ciki yana daga shiga zuwa fita, bout na waje kuma daga fita har kudar ta dawo. A cikin bouts 755 na ciki, ziyara ta ɗauki matsakaicin sakan 4.9. Yayin dawowa, matsakaicin nisa daga iyakar ya kasance milimita 10.4. Kasa da 4% na bouts 793 ne suka ketare har zuwa dayan gefen hanyar gaba ɗaya.

Waɗannan lambobi biyun na ƙarshe suna bayanin bouts ne, ba ɗaruruwan kudan da suka kasance masu zaman kansu ba. Bambancin yana da muhimmanci domin kuda guda na iya bayar da bouts da yawa.

Dawowar ba kawai martanin juya zuwa sama da iska ba ne

Gwaje-gwaje da yawa sun gwada bayanai mafi sauƙi.

Da farko, masu binciken sun sauya abin da ke faruwa **a tsawon** hanyar yayin da kuda ke tafiya zuwa sama da iska. Warin zai iya ƙaruwa yayin kusantar tushen kama-da-wane, ya kasance daidai, ko ya ragu. Kudan sun nuna hanyoyi iri ɗaya a duk yanayi ukun. Saboda haka wata ka’ida mai sauƙi kamar “ci gaba zuwa inda warin ke ƙaruwa” ba za

ta iya bayyana edge tracking a wannan na'ura ba.

Daga nan suka mayar da **gefen gefe** na hanyar ya zama mai laushi ta hanyar Gaussian profile, inda ƙarfi ya canza a hankali maimakon ya kunna ko kashe kwatsam. Kudan sun fi taruwa kusa da gefen da ƙarfi ya fi saurin canzawa, ba a tsakiyar inda warin ya fi ƙarfi ba. Saboda haka abin nuni mai muhimmanci shi ne canjin gefe wanda ke nuna wata iyaka mai tasiri, ba dole sai warin ya ƙaru a hanyar zuwa tushen ba.

Wannan ba yana nufin cewa gradient na ƙarfi ba ya da muhimmanci a yanayi ba. Yana nufin cewa ƙaruwa zuwa tushen ba ta zama dole ga wannan hali a yanayin da aka gwada ba.

Masu binciken sun kuma sauya alkiblar hanyar. Kungiyoyi daban sun bi hanyoyi na digiri 0, 45 da 90, sannan wata ƙungiya ta haɗu da hanyar da ta yi tsalle zuwa gefe bayan kudan sun fita. Adadin kudan a ƙungiyoyin ya kasance 40, 21, 20 da 24. Hanyoyinsu a waje sun sauya tare da geometry. Ka'ida gaba ɗaya kamar "kullum juya zuwa sama da iska" ba za ta iya bayyana wannan sassauci ba.

A wannan tsarin, wari ya isa eriya biyu a cikin kusan millisecond biyu. Haɗa kunnawa na optogenetic a bangarorin biyu da iska ya iya sake samar da hali mai kama da edge tracking. **Optogenetics** na amfani da furotin masu amsa haske domin sauya aikin wasu sel da aka zaɓa. A nan, sakamakon yana nuna cewa bambancin lokacin isowar wari tsakanin hagu da dama ba ya zama dole ga wannan hali. Ba ya sa kwatanta bangarorin biyu ya zama mara amfani ga dabbobin da ke motsi cikin 'yanci a wasu gajimaren wari.

Vector ya fi taswira ƙarami

Vector yana nufin alkibla tare da girma. Abin da ya fi amfani a matsayin bayanin da aka adana a nan shi ne alkibla: wace hanya ya kamata kudar ta juya domin ta kai ga iyakar gajimaren wari? Binciken bai sami shaida cewa kudar ta adana cikakken tsarin gajimaren ko matsayinta a cikinsa ba.

Da farko marubutan sun ƙirƙiri hanyoyi na wucin gadi ta hanyar gauraya sassan motsin kudan na gaske. Sun ɗauki tsawon tafiya da kusurwar juyawa da aka lura da su a bazuwar, sannan suka haɗa su. Wasu daga cikin waɗannan masu tafiya na kwaikwayo daga baya sun sake samun iyakar warin, amma sun yi nisa fiye kuma hanyoyinsu ba su kai tsaye kamar na kudan gaske ba. Ko da ƙara halin kudan na yau da kullum na karkata zuwa sama da iska bai sake samar da gajerun dawowa masu kai tsaye ba. Saboda haka halin gaske ya ƙunshi ƙarin bayanin alkibla fiye da gaurayen bazuwar na motsi iri ɗaya.

Daga baya masu binciken suka gina model mai yanayi biyu: **barin iyaka** da **komawa iyaka**. Waɗannan ba sunaye ba ne ga kowane lokaci a ciki ko wajen wari. Dokokin tuƙi ne guda biyu da za su iya sauyawa yayin da kudar ke motsawa.

Kowane ketare iyaka yana ba model wani alkibla da zai tuna. Lokacin fita, samfurin ya sabunta alkiblar da ake amfani da ita yayin barin iyaka. Lokacin shiga, ya sabunta wata alkiblar dawowa daban: a takaice, "lokacin da na sami iyakar, wannan ce hanyar da nake motsawa." A dawowa na gaba, wannan alkiblar da aka tuna tana karkatar da motsin kudar kwaikwayo zuwa gefen.

Masu binciken sun daidaita samfurin da hanyoyin daga corridor na digiri 0, 45 da 90. A kwatancen taƙaitacce, kuda na gaske 72 da simulations 75 sun samar da kididdigar hanyoyi masu kama. Lokacin da aka cire alkiblar dawowa da aka koya a lokacin shiga, bibiyar ta zama ƙasa da inganci a duk alkiblan corridor. Wannan yana goyon

bayan amfanin ƙwaƙwalwar alkiblar shiga; ba ya tabbatar cewa kwakwalwar kuda tana aiwatar da equations na model a zahiri.

> **Me ake nufi da "memory" a wannan takarda?**
>
> Masu binciken ba su karanta wata kibiya da aka adana kai tsaye daga kwakwalwar kuda ba. "Directional memory" wani fassara ne da hali, model da ma'aunin jijiyoyi ke goyon baya. samfurin yana nuna cewa wasu 'yan alkiblu masu sauyawa na iya sake samar da muhimman kididdigar hanyoyi. Ba ya tabbatar cewa kudar tana aiwatar da equations a zahiri, ko kuma cewa wata ƙungiyar jijiyoyi guda ɗaya ita ce wurin adanawar.

Karin gogewa da wani sashe na digiri 45 mai alkibla akasin na farko ya sauya halin daga baya a kuda 10, tare da simulations na model 29. Wannan ya sa bayanin alkibla ya fi takamaiman bayani da aka ƙirƙira bayan ganin sakamako, amma har yanzu yana kasancewa fassara da ta dogara da model.

Ma'aunin alkiblar da ake fuskanta da burin da ake nema yanzu

Binciken daga nan ya auna tare da katse aikin **central complex** na kwakwalwar kuda, wani yanki da ke da hannu a navigation.

> **Sigina biyu masu ayyuka daban**
>
> EPG da FC2 sunaye ne na ƙungiyoyin jijiyoyi biyu a central complex. Aikin EPG yana kama da karatun compass: yana bibiyar alkiblar da kudar ke fuskanta yanzu idan aka kwatanta da iska. Aikin FC2 yana da alaƙa da alkiblar da kudar ke ƙoƙarin tafiya. Wata hanyar sarrafa juyawa a ƙasa na iya kwatanta alkiblar yanzu da wannan buri. Binciken ya gwada ƙungiyoyin biyu, amma bai nuna cewa ɗayansu kaɗai na adana dukan ƙwaƙwalwar ba.

Jijiyoyin EPG suna ɗauke da siginar alkibla: tsarin aikinsu yana bibiyar alkiblar da kudar ke fuskanta idan aka kwatanta da wani abin nuni daga waje. Ta amfani da calcium imaging, wato hanyar gani ta kai tsaye ba ce amma tana wakiltar aikin jijiyoyi, masu binciken sun gano cewa matakin aikin EPG ya bi alkiblar kudar idan aka kwatanta da iska yayin edge tracking. Wannan nazari ya yi amfani da gwaje-gwaje 16 daga kuda 9.

Domin hana jijiyoyin EPG aiki, masu binciken sun sa su bayyana **GtACR1**, wata tashar anion da hasken kore ke kunnawa. LED ya ci gaba da kunne a duk gwajin, yana kunna wannan tashar kuma yana rage aikin jijiyoyin da aka zaɓa; irin wannan hasken bai lalata halin kudan control na kwayoyin halitta ba.

Lokacin da aka hana jijiyoyin EPG ta wannan hanya, kuda na gwaji 12 sun yi dawowa kai tsaye ƙasa da inganci idan aka kwatanta da kuda control 6. Kayyadadden abin da za a iya cewa shi ne cewa ma'aunin alkibla da aikin EPG ke ɗauka ya zama dole domin ingantaccen edge tracking a yanayin da aka gwada. Wannan ba shaida ba ce cewa jijiyoyin EPG su kaɗai ne suka adana alkiblar iyakar.

Jijiyoyin FC2 sun nuna wata alaƙa dabam. Aikin ƙungiyarsu yana da alaƙa da burin navigation na yanzu kuma

ya nuna zuwa iyakar gajimaren wari kafin juyawa a gwajin. Imaging ya yi amfani da kuda 6, yayin da kwatancen silencing ya yi amfani da ƙungiyoyi masu kuda 9 zuwa 14, gwargwadon nazarin. Silencing ya rage ingancin edge tracking.

Hali, sauya geometry na gajimare, model da aka daidaita, da gwaje-gwajen katse jijiyoyi biyu suna goyon bayan sassa daban-daban na bayanin directional memory. Tare suna goyon bayan ƙaramin alkiblar buri a wannan gwaji da aka sarrafa, ba cikakkiyar taswira ko wani wurin adanawa a sel da aka tabbatar ba.

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Wannan shaida ce daga hanyoyi daban-daban da suke haɗuwa, ba hoto kai tsaye na sarkar dalili ba. Aikin EPG ya samar da ma'aunin alkibla da ake buƙata. Aikin FC2 ya dace da alkiblar buri kuma ya zama dole domin ingantaccen hali. Gwaje-gwajen ba su gano wani memory "engram" guda ɗaya ba, kuma ba su tabbatar cewa synapses na FC2 ne suka adana alkiblar a zahiri ba.

A matsayin misalin fahimta na ɗan adam, ka yi tunanin ka fito daga wata siririyar gajimare ta hazo yayin da iska mai ɗorewa har yanzu tana gaya maka inda arewa take. Compass zai iya gaya maka inda kake fuskanta, amma komawa ga hazon yana kuma buƙatar ka tuna da alkiblar gefensa. Kwatanta alkiblar da kake fuskanta yanzu da alkiblar da kake son zuwa tana gaya maka inda za ka juya. Wannan shi ne rabon aiki da binciken ke ba da shawara tsakanin siginar EPG da FC2. Misali ne na bayani kawai, ba shaida cewa mutane suna amfani da sel ko algorithm iri ɗaya ba.

Ƙwaƙwalwar ta dogara da aiki, ba lokacin wari kaɗai ba

A wani gwajin replay, kudan sun karɓi jerin lokutan wari iri ɗaya da na baya, amma an raba lokacin daga abin da suke yi a wannan lokacin. Son alkiblar da aka koya ya raunana daga bout zuwa bout. Wannan yana goyon bayan sabuntawa **operant**, wato wanda yake da alaƙa da aiki: abin da ya fi muhimmanci ba wai sauraron jerin wari kawai ba ne, sai dangantakar da ke tsakanin warin da motsin kudar.

Denominator ya sauya tsakanin waɗannan nazarce-nazarce. Extended bayanai panels suna da kuda 8 ko 9 gwarg-wadon kwatancen; jerin bouts a jere ya yi amfani da kuda 8; trajectory panels suna buƙatar aƙalla effective entries 10; sannan paired model panels suna amfani da trajectories na simulation 21 waɗanda su ma suka cika wannan sharadin shiga. Waɗannan ba samfurin kuda takwas guda ɗaya da aka haɗa ba ne.

Gajimare mafi rikitarwa ya taimaka, amma har yanzu na kama-da-wane ne

Masu binciken sun kuma sake kunna wani gajimaren wari da aka rikoda a baya wanda ya fi rashin daidaito. Sun faɗaɗa shi sau biyar a sarari da lokaci domin kudan da aka ɗaure su iya haɗuwa da shi sau da yawa. **Kuda 10 cikin 12** sun kai cikin milimita 50 na kama-da-wane daga tushensa.

Wannan ba yana nufin kuda goma sun sami wani tushen wari na gaske a sararin waje ba. Aiki ne a cikin replay da aka sarrafa na gajimare mai kama da na halitta.

Ga kowane nau'in dynamic plume, samfurin ya samar da trajectories 2,000. Kwatancen scaled plume ya nazarci 1,850 daga cikin 2,000 bayan an buƙaci effective entry kuma aka cire trajectories da suka fara kusa da tushen sosai. Ƙwaƙwalwar ta fi taimakawa kusa da tushen, inda haɗuwar jere-jere ta ci gaba da riƙe tsarin alkibla mai ma'ana, kuma ta fi ƙarancin taimako a yankin da ya fi rikicewa a ƙasa da iska.

Wannan ƙayyadewa wani ɓangare ne na sakamakon. Ƙaramin bayanin alkibla zai taimaka ne kawai idan duniya ta ci gaba da kasancewa mai isasshen daidaito har haɗuwar da ta gabata ta ba da wani bayani mai amfani game da ta gaba.

Abin da binciken bai nuna ba

- Bai nuna **cikakkiyar taswirar sarari** a kwakwalwar kuda ba.
- Bai nuna **free flight** a cikin gajimaren wari na halitta da ba a canza ba.
- Bai tabbatar cewa duk navigation da wari ke jagoranta tana amfani da wannan dabara ba.
- Bai nuna cewa jijiyoyin EPG ko FC2 su ne keɓaɓɓen wurin adanawar ƙwaƙwalwar a zahiri ba.
- Bai mai da model da aka daidaita ya zama algorithm na halittar kudar a zahiri ba.
- Ba za a iya ɗaukar sakamakon kai tsaye zuwa navigation na ɗan adam ba.

Binciken ya fi ƙarfi inda ikirarinsa ya fi takamaimai. Closed-loop control ya ba masu binciken damar sanin daidai

kowace haɗuwa da wari. Daga nan sauya geometry, replay, modeling, calcium imaging da silencing suka gwada sassa daban-daban na bayani guda ɗaya. Amma ƙungiyoyin kudan da aka yi amfani da su a behavioral, imaging da silencing sun bambanta; ba a ƙayyade sample sizes tun farko ba; ba a randomize ko blind tattara bayanai da nazarinsu ba; kuma kasa da 10% na kudan da aka ɗaure an cire su saboda matsalolin acclimation, amsawa ko tracking.

Waɗannan iyakokin ba sa goge abin da aka lura da shi. Suna bayyana iyakar abin da za a iya cewa game da shi.

Taƙaitaccen bayani

Kudan 'ya'yan itace da aka ɗaure, suna tafiya a cikin hanyar wari ta kama-da-wane, sun riƙa komawa zuwa iyaka bayan sun bar warin a baya. Sauye-sauyen ƙarfi da geometry na corridor, model mai sauya yanayi da aka daidaita, neural imaging da optogenetic silencing suna goyon bayan bayanin cewa kudar tana amfani da ƙaramin alkibla da ta tuna maimakon cikakkiyar taswira. Jijiyoyin EPG sun samar da ma'aunin alkibla da ake buƙata, yayin da aikin FC2 ya dace da alkiblar burin navigation na yanzu. Sakamakon ya takaita ga gwajin tafiya da aka sarrafa; bai gano wurin adanawar ƙwaƙwalwar a matakin sel ba kuma bai nuna cewa ana amfani da lissafi iri ɗaya a free natural flight ba.

Binciken ba tare da ƙarin gishiri ba

Abin da takardar ta nuna: A cikin closed-loop tethered assay, kudan sun yi dawowa kai tsaye zuwa iyakokin wari na kama-da-wane da ba za su iya jin warinsu a lokacin ba. Behavioral controls da yawa, modeling da neural perturbations suna goyon bayan dabara mai dogaro da vector.

Abin da aka fassara daga bayanan: Halin yana amfani da ƙaramin directional memory, kuma aikin ƙungiyar FC2 yana wakiltar burin navigation na yanzu. Ba a karanta abin da ƙwaƙwalwar ta ƙunsa kai tsaye ba.

Abin da bai nuna ba: Cikakkiyar taswirar tunani, dabarar wari ta duniya gaba ɗaya, aikin free flight a gajimaren wari na halitta, wani wurin adanawar ƙwaƙwalwa guda ɗaya, ko wani daidaitaccen analog na ɗan adam.

Manyan iyakoki: Nau'in dabba guda ɗaya da na'ura da aka sarrafa; ƙungiyoyin kudan da units of nazari daban-daban tsakanin gwaje-gwaje; siginar calcium da ba kai tsaye ba; gwaje-gwajen necessity waɗanda ba su tabbatar da sufficiency ba; da kuma gajimaren da ya yi kama da na halitta amma aka replay da scale shi.

Yaya yawan amincewa ya kamata mai karatu gaba ɗaya ya yi? Babban amincewa cewa directed-return phenomenon na gaske ne a wannan na'ura kuma aikin central complex mai alaƙa da heading da goal yana da muhimmanci. Matsakaicin amincewa ga model a matsayin ƙaramin bayani mai amfani. Ƙaramin amincewa ga duk wani ikirari da ya faɗaɗa wannan sakamakon ba tare da canji ba zuwa sararin waje ko ya kira shi cikakkiyar taswira.

Majiyoyi

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