Strategy TDNTupleAgt:   
How does it work for 2048?

## Literature

[[Jaskowski16]](file:///C:\WUTemp\FH-MassenDaten\svnSoma\trunk\doc\CaseStudies.d\201314.d\CIG2014\MCTS.literature\2048\Jaskowski2016-2048.pdf)

[[SzubertJaskowski-CIG2014]](file:///C:\WUTemp\FH-MassenDaten\svnSoma\trunk\doc\CaseStudies.d\201314.d\CIG2014\MCTS.literature\2048\paper2048-SzubertJaskowski-CIG2014.pdf)

[Konen2017b] ([TR-TDNTuple.tcp](file:///C:\user\wolfgang\www\Optimierung\TR_GBG\TR-TDNTuple.tcp))

[[Galitzki17]](file:///C:\user\datasets\Vorlesungen\FHK\DiplomArb\2014\BA%20Galitzki\BA-KevinGalitzki-final-2017.pdf.lnk)

## Nomenclature

|  |  |
| --- | --- |
| st | state at time t |
| pt ∈ [-1,+1] | player **to move** at time t. For 1-player games: always pt=+1. |
| at | action taken at time t |
| s’t+1 | **afterstate** at time t+1 (applying at to st, but before random element) |
| st+1 | state at time t+1 (afterstate plus random element) |
| Rt+1 | total reward ( game score) for state st+1 at time t+1 (referring state: st) |
| rt+1 = Rt+1 - Rt | partial reward when moving from stto st+1 (referring state: st) |
| V(st+1) | game value, the agent’s expectation of the sum of future rewards (beyond rt+1) |

Initially, we had not yet the afterstate logic of [Jaskowski16] integrated, but meanwhile it is part of the new TDNTuple2Agt (switch AFTERSTATE). For deterministic games: s’t+1= st+1.

We describe the TDNTupleAgt-logic for both 1-player and 2-player games, to keep it general.

The total reward Rt+1 is the reward relative to st. That is, when player pt moves in st and the reward from the environment is =-1 (player pt+1 has lost), then Rt+1 (with st as reference) is (-1)\*(-1) = +1 (player pt has won). This is for 2-player games. For 1-player games, the reward relative to st is always equal to the reward from the environment.

For games which give a reward only in the terminal state (like TTT or Hex), the “expectation of the sum of future rewards” in V(st+1) is identical to the “expectation of the total reward”, i.e. the game value.

Currently V(st+1) is for 2-player games always the game value from the perspective of the 1st player (“X”). This is not very logical, since Rt+1 is measured with respect to referring state st and player pt. We will try in TDNTuple2Agt to get a more homogeneous realization of V(st+1).

## New Target Logic

Since the TDNTupelAgt did not work at all for 2048, but [Jaskowski16] had success with TD-Ntuple-learning, we re-investigated the target logic here and there and coded with switch NEWTARGET==true a version more similar to [Jaskowski16].

### getNextAction(st)

returns arg maxa CurrentScore(st,a), where CS = CurrentScore is:

1. OLD target logic (NEWTARGET==false)
   1. st+1 not terminal: CS = pt \* V(st+1)  
      (For 1-player games, this simplifies to V(st+1))
   2. st+1 terminal: CS = Rt+1 (with st as referring state)  
      (For 2-player games which are terminated by a winning move, like TTT or Hex, this simplifies to Rt+1=+1)
2. NEW target logic (NEWTARGET==true)
   1. CS = rt+1 + γ pt V(st+1)   
      (For 1-player games, this simplifies to rt+1 + γ V(st+1))

This is for the case when no random action is requested. If a random action is requested, each CurrentScore(st,a) will be set to a different random number, so getNextAction will return a random action.

The discount factor γ was missing in the old target logic of getNextAction(), for no specific reason. It is however sensible to include it in getNextAction() if we have it in trainAgent() (!). The impact on the results achieved so far is minimal, since we had nearly always γ=1.

### trainAgent(s0)

Learn or train the agent from one episode (an episode is a self-play-game starting from s0 and ending with a terminal state)

t=0

while (st not terminal) {

at = getNextAction(st)

st+1 = advance(st, at)

1. OLD target logic (NEWTARGET==false):
   1. st+1 not terminal: TDupdate(T= γV(st+1), s­t, λ)
   2. st+1 terminal: TDupdate(T= pt\*Rt+1, s­t, λ)
2. NEW target logic (NEWTARGET==true):
   1. TDupdate(T= pt rt+1+γV(st+1), s­t, λ)

}

if (NEWTARGET==true) TDupdate(T= 0, s­t, λ)

In the OLD target logic, the target for a pre-final state is to **predict the total reward** (times pt ∈ {-1,+1} for 2-player games, that means the total reward from the perspective of player +1).  
In the NEW target logic, the target is to **predict the extra reward** pt rt+1 for a pre-final state (that is a small number compared to the total reward in the case of 2048) and 0 for a final state.

This is for the case w/o random moves (ε=0).   
If ε>0, getNextAction() will be requested to return with probability ε a random action and (if learnFromRM==false) no TDupdate takes place after such a random action.

## Current drawbacks of TDNTupleAgt

Experiments with TDNTupleAgt and the game 2048 revealed that the current agent “TD-NTuple” has a number of drawbacks and deficiencies and can by no means create anything similar to [Jaskowski16]. These drawbacks are:

1. The current target logic is suspicious for games with continuous rewards like 2048. We implemented a new target logic (NEWTARGET==true) along the lines of [Jaskowski16] (see above), but this does not yet lead to success.
2. If we switch off the sigmoid (as it is done in [Jaskowski16]), we get with NEWTARGET after many training games diverging (infinite) weights (and thus a crash). What has to be done to avoid the unlimited weight growth?
3. [Jaskowski16] describes a better learning scheme with **afterstates s’** which should be implemented in TD-NTuple-2. We may use StateObservationNondeterministic for that purpose.
4. If we increase in 2048 the random n-tuples (number N, length L) from (N,L)=(10,3) to (10,4), the number of weights increases by a factor of 15 (due to the 15 position values in each n-tuple cell). This should cost more memory, but not more runtime. Instead we experience in training **runtime increase by a factor of 30** (!!??). Why is this so and can it be avoided by a better implementation? – The reason is that updateElig becomes very slow since there are as many traces as weights, and after a while many of them are non-zero. And that updateElig was erroneously called in NTupleValueFunc::calcScoresAndElig even in case λ=0 (now fixed in NTupleValueFunc 🡪 the case λ=0 becomes fast). But the problem remains for λ>0.
5. The current way of calculating eligibility traces in TDNTupleAgt is bound to be very slow for games like 2048 having many moves in one episode. [Jaskowski16] suggests another way of doing it by keeping only those traces where λk ≥ 0.1. We implemented this in TDNTuple2Agt.
6. Johannes Kutsch [reports a disturbing issue](file:///C:\Users\wolfgang\AppData\Roaming\Microsoft\Word\mai-von-Kutsch-06\mai-von-Kutsch-06.msg) when training TDNTupleAgt for 2048: When training for 106 episodes with 20 3-tuples, there was an increase up to score 30.000 until episode 990.000, but then a sudden decrease to score 1.000 in the very last episodes. Why?
7. When all the deficiencies are resolved: Try to simplify the code where possible, in order to keep it maintainable.

To experiment on these issues, we create the copy classes TDNTuple2Agt, NTuple2ValueFunc and NTuple2 in subdir controller/TD/ntuple2 which we can modify and test in parallel to the former classes in subdir controller/TD/ntuple.

We first start to work on issues 4. and 5. For this, it is necessary to review the exact calculation of the n-tuple score in TDNTupleAgt (and connected classes).

It [turned out](#issue2And6), that these issues together with a few (other) bug fixes found when [#Debugging TDNTuple2Agt](#_Debugging_TDNTuple2Agt), solved issues 1., 2. and 6. as well. Finally, we will fix issue 3. as well in [#Afterstate Logic and Debugging](#_Afterstate_Logic_and), so that we have all issues solved when we solve issue 7. as well.

## N-tuple score

**getScoreI()**, the n-tuple score function in class NTuple2ValueFunc, computes:

OLD **and** NEW target logic (NEWTARGET==false/true)

with S(st): the set of all states symmetric to st (including st itself), NS = |S(st)|

Indi(s): the index into the look-up table Vi[] of n-tuple i=1,…,m, given state s.

The **update function** **in case λ=0** (no eligibility trace) for each n-tuple i=1,…,m is

OLD target logic (NEWTARGET==false)

NEW target logic (NEWTARGET==true)

with σ’(st): the derivative of the sigmoid σ() w.r.t. its argument at state st, that is (1-V2(st)) in case of σ()=tanh() and 1 in case of no sigmoid (σ()=1),

δt: the delta signal “T – V(st)” where the target T is the first argument of [TDupdate](#TDupdate) above.

**Special case no sigmoid and α=1**: In this case we have σ’(st)=1 and the NEW target logic update rule will add δt/(mNS) to each Vi. Plugging this into the getScoreI-equation we see that the update rule with α=1 has consistently (for each number of n-tuples) the meaning: “Let become immediately the target ” :

This is why the scaling with 1/(mNs) (m=number of n-tuples) in the update rule makes sense.

(We note in passing that the OLD target logic misses the factor 1/mNS in the update rule, so a hypothetical update with α=1 will overshoot the target by a factor mNS (e.g. mNS = 80 for an 8-fold symmetry and 10 n-tuples).)

There was a possible bug in this update rule (see [below](#bugUpdateFormula)), which happened when two states in would activate the same LUT-entry of an n-tuple. We solved this by adding a bookkeeping mechanism which inhibited the update if it had been already updated once by another member of .

## Update function in case λ ≥ 0

The general TD(λ) rule for weights wt is:

Normally, this formula is realized in TD(λ)-algorithms with the help of eligibility traces and t0=0 is used. But eligibility traces are unpractical (prohibitively slow) in cases like 2048 (long episodes, millions of weights).

[Jaskowsi16] has the brilliant idea to use instead a finite horizon t0=max(t-h, tmin),[[1]](#footnote-1) that is, we use in the TD(λ) formula above only the first h+1 terms (at most). If we choose then we retain only those terms with λk ≥ 0.1.

For n-tuple score: The weights wt are the entries Vi in the lookup tables. The gradient boils down to for all weights with and to 0 for all other weights. Thus we get the update rule (similar to [Jaskowsi16], Algorithm 1):

For k=t downto t0

For i=1 to m

In order to compute this at time step t, we have to store the states , k=t,…,t0 (in order to calculate the indices for all states equivalent (symmetric) to ) and the sigmoid values .

If is the state, we can start from t=0 theoretically. But if is replaced by the afterstate as done by [Jaskowski16], then we do not have the afterstate , therefore we start to learn only for t>0. This is the same reason why we have the “1” in t0=max(t-h,1).

Implementation: Use java.util.LinkedList for storage within horizon: we store in this list h+1 objects of class EquivStates containing for each afterstate the array int[][] equiv coding and the value .

The good thing: We need no longer the eligibility traces, their storage, and the time for resetting them 🡪 much faster execution when LUTs are large!

## Debugging TDNTuple2Agt

* OK: We realized that even with epsilon=0 frequent **random moves** occurred (??, which should not be!). The reason was suspicious (wrong) code around ‘progress’ and ‘randomSelect’ in TDNTuple2Agt::getNextAction (and likewise in TDNTupleAgt). – Now replaced with the simpler code

randomSelect = (rand.nextDouble() < m\_epsilon) ,   
which is used in TDAgent::getNextAction as well. With this, we observe no more random moves if m\_epsilon==0. Changed in TDNTupleAgt as well.  
The following plot shows the old and wrong random move rate (ε is constant, ‘progress’ is the proportion of all training games):  
   
Remember: When training a stored agent anew, the stored parameters for εinit and εfinal will probably not be valid or useful anymore. If we want a similar behavior, we have to select other values.   
For ε not being constant, see the [plots and text below](#_Parameter_at_time).

* With no sigmoid and ALPHA=1.0, we should get after each weight update a value being **identical to the target** used in that update. We find this valid when running the program with USESYMMETRY==false, but it is **violated** if USESYMMETRY==true. Why?? – This was a **fundam****ental problem in the formulas**: Whenever two equivalent states lead to the same Index for a certain n-tuple (e.g. 0, not activated at all), then the LUT entry for that Index will be updated twice. When later the new value (getScoreI) is calculated, the LUT for the same Index will be added twice as well. This leads to 4x delta\_w, where it should be only 2x delta\_w. – How to fix: When updating for a set of equivalent states, start with an array trainCounter[\*]=0. When a certain index is updated, increment its trainCounter. Update is only done if trainCounter[Index]==0. This leads perfectly to Vnew = Target in the case no sigmoid and ALPHA=1.0.
* The good news: With this new approach we get better results: A quick run with only 10k training games leads to avg. score 30k, highest score 60k in 50 eval games. The 2048 tile is reached in 36 out of 50 games.
* Drawback of the trainCounter remedy: Having to reset trainCounter[] for each n-tuple prior to updating slows down the whole process: for 500 training games from 2.5 sec to 51 sec (!!). We implemented a faster way with LinkedList indexList in NTuple2. This is much faster: only 7 sec instead of 51 sec. Results seem slightly worse, but this may be due to statistical fluctuations.
* It seems that the new changes and bug fixes also solve the issues 2. (**infinite weights**) and 6. (JK’s issue of **drop down in score** near the end of the training games) in the list [#Current drawbacks of TDNTupleAgt](#_Current_drawbacks_of) 🡪 at least we do not observe both effects, when we train agent ‘10 4Tupel 30k TDNT2 indexList.agt.zip’ for 40.000 games. See [training plot here](file:///C:\Users\wolfgang\AppData\Roaming\Microsoft\Word\TDNTuple2Agt-10%204tuple%2040k.png).
* When having this agent playing, it is nice to see that (at least for some time) the **highest tile stays constantly in a corner**. This behavior was found through learning, it was not prescribed by any form of heuristics (!). When doing a quick eval, the highest-tile statistics fluctuates somewhat, but we get quick evals with 41 ‘2048’-tiles and even 2 ‘4096’-tiles out of 50 games.
* OK: Small bug: the number of training games is not saved when saving TDNTuple2Agt. – Fixed: suitable switch if(… || td instanceof TDNTuple2Agt) added in XArenaMenu::loadAgent.
* OK: Apparent bug: After the changes in TDNTupleAgt and TDNTuple2Agt, there seems to be something wrong with TTT: (a) not always 100% success (sometimes -0.2, sometimes -0.45) and (b) the first move on the empty board has all V(s)=0. Why?? There should be nothing different in TDNTupleAgt, except the new random move calculation. – This is no bug, the behavior has to do with this new random move calculation, which means that εinit=0.3, εfinal=0.0 triggers much less random moves than before. If we change to εinit=1.3, εfinal=0.0, we get very much the same results as before.
* OK: Is it still disturbing that the empty board has all V(s)=0 ? (The exact values are something like 1e-17, if we inspect them in debugger). Observation: If we switch from gb.chooseStartState01() in XArenaFuncs::train() to gb. getDefaultStartState (), we get a non-zero V(s). – It should not disturb us: an empty board with all V(st+1)=0 is not wrong (!). Because Minimax as an exact agent has exactly this V(st+1)=0. That is, we can reach a tie with EVERY initial move.
* OK: Another (upcoming) small problem with TDNTuple2Agt: in the new afterstate logic it will learn only for t>0, which is inferior for the first move in TTT. – We ‘fixed’ it with the logic, that the afterstate logic is ONLY allowed for nondeterministic games. For deterministic games like TTT or Hex it is hardcoded that AFTERSTATE==false. With this setting in effect, we learn for the first move as well.
* OK: **Is for Hex gb.chooseStartState01()** in XArenaFuncs::train() the right way to do it? – Probably yes! A good agent should not only win when it starts the Hex game, but it should also win when the opponent starts with one of the losing moves. If we start in training always from the default start state (empty board), it is very likely that self-play (after a while) will always start with one of the winning moves. Then it will not learn to exploit possible errors of the opponent in his first move. We have now the possibility in the OtherPar tab to check or uncheck the ‘Choose Start 01’ box.
* OK: Made a **tougher evaluator for Hex** (evalMode==10): (a) one game from empty board and (b) N games, when 1st player makes one of the N losing moves[[2]](#footnote-2) and the agent plays 2nd player. The evaluator calculates the average win rate for the agent. Ideally it should be 100%. – The drawback of this evaluator is: For each new Hex board size, the losing moves have to be determined manually. This makes it less easy to go to the next level.
* OK: implemented [afterstate logic](#_Afterstate_Logic_and)
* OK: member randomSelect is now part of Types.ACTIONS 🡪 simpler bookkeeping in train functions.

### Parameter settings in different software states

#### Parameter at time of writing BA Galitzki / Kutsch

ε and resulting random move rate: in TDNTupleAgt the ‘suspicious’ form

where the two numbers shown for ‘eps’ are εinit to εfinal. The strange form in the case ‘non-constant ε’ results from a strange ε-change rule in the form of a ‘half-sigmoid’ which drops quite fast from εinit/2 (which is wrong) to values close to εfinal. See [TDNTuple-eps.R](file:///C:\user\datasets\Vorlesungen\FHK\DiplomArb\2016\BA%20Kutsch\TDNTuple-eps.R) for details. In TDAgent: the random move rate is linearly decreasing from εinit to εfinal.

‘Learn from RM’: always false

‘Choose Start 01’: always true, that is 50% default start state, 50% one of the 1-ply moves start

AFTERSTATE: always false

[α-decay](#_Alpha_decay): exponentially decreasing from αinit to αfinal in TDNTupleAgt and TDAgent.

#### Parameter since 2017-08-20

ε and resulting random move rate: (at least) two options exist:

We currently implement only **epsL****inear**, since the resulting random move rates are not dramatically different for epsLinear and epsSigmoid. We do this consistently for all three agents TDAgent, TDNTupleAgt, and TDNTuple2Agt. Note that initial εinit>1 are also sensible settings for certain random move rate profiles (they are for an initial period saturated at 100% random moves). Likewise, εfinal<0 is possible as well: this results in a final period saturated at 0% random moves.

‘Learn from RM’: true/false in ‘Other pars’ tab

‘Choose Start 01’: true/false in ‘Other pars’ tab

AFTERSTATE: false for all deterministic games. true/false in ‘NT pars’ tab for nondeterministic games (currently only 2048)

[α-decay](#_Alpha_decay): exponentially decreasing from αinit to αfinal in TDNTuple[2]Agt and TDAgent.

## Hex and TDNTupleAgt Debugging

There are two problems with Hex and TDNtupleAgt

* OK: When re-loading a trained agent from Kevin Galitzki, it is **re-loaded with withSigmoid==false** (although at the time of training only withSigmoid==true was allowed). Why?? As a consequence we get unusual high values in InspectV. – This was due to a bug in the loading mechanism: Parameter tdPar.hasSigmoid() would get the right value during loading, but m\_Net.withSigmoid was not updated during load. Now fixed: suitable call to td.setTDParams() in XArenaMenu::loadAgent will set m\_Net.withSigmoid. Likewise, we need m\_Net.useSymmetry to be set properly: suitable call to td.setNTParams() in XArenaMenu::loadAgent. We had to add a new function NTupleValueFunc::setUseSymmetry. The same changes were done for NTuple2ValueFunc and TDNTuple2Agt.[[3]](#footnote-3)
* When re-training an agent for 5x5 boards or higher, the evaluation will not return (at least not for a long time). Probably it starts a Minimax evaluation which is too big to fit in memory. – Symptomatic remedy: Set Other Pars – Train Eval Mode = 0 prior to start of train.[[4]](#footnote-4) Then we do an evaluation with MCTS as counterpart, which is fast. However, it is less accurate.

## Afterstate Logic and Debugging

We add a runtime switch

boolean AFTERSTATE

in TDNTuple2Agt and decide based on this whether we expect StateObservation objects to be actually instances of StateObservation (AFTERSTATE==false) or StateObservationNondeterministic (AFTERSTATE==true).

**Important**: **Use AFTERSTATE=false for deterministic games**, only in this way we can learn for t=0 as well, and it might be important in games like Hex or other to start with the right initial move.   
**Use AFTERSTATE=true for nondeterministic games**, this should lead to a better value function, because the set of possible afterstates in a game like 2048 is much lower than the set of possible states. This allows faster learning.

The following things need to be changed if we implement AFTERSTATE==true:

### getNextAction

Assert that NewSO is an object of StateObservationNondeterministic and in the loop over actions replace

NewSO.advance(actions[i]);

with

NewSO.advanceDeterministic(actions[i]);

Then NewSO will contain the **afterstate** s’ (before adding a random tile in the case of 2048). We calculate the score r + p\*V(s’) (where p=+1/-1 is the player for 2-person games).

The rest remains the same.

### trainAgent

Assert that so is an object of StateObservationNondeterministic and in the while loop replace

so.advance(actBest);

nextBoard = m\_Net.xnf.getBoardVector(so);

with

so.advanceDeterministic(actBest);  
 nextBoard = m\_Net.xnf.getBoardVector(so);  
 so.advanceNondeterministic(actBest);

This lets nextBoard become the board vector of an **afterstate** s’ (so.advanceDeterministic) and in the next round, after

curBoard = nextBoard,

curBoard will be the board vector of an afterstate as well. On the other hand, so in line 3 is the **state** s’’ (with random tile added) which we need to continue and to decide whether the game is over or not.

Additionally, in case AFTERSTATE==true, set in the initialization part **before** the while-loop curBoard=null. Perform in trainNewTargetLogic the weight update only if curBoard!=null. This ensures the “if (t>0) …” part in [Jaskowski16], i.e. no update in the very first move of an episode.   
On the other hand, if AFTERSTATE==false, we keep the old line

**int**[] curBoard = m\_Net.xnf.getBoardVector(so);

Then the function NTuple2ValueFunction::update() is called even in the first pass, and this is in effect the same as if we replace in TD(λ)UPDATE() in [Jaskowski16] the element max(t-h,1) with max(t-h,0). This is the desired behavior for deterministic games, where we want an update for the first state (empty board) as well.

The rest of the code in trainAgent() remains the same.

As a whole, the changes which we need to implement for AFTERSTATE==true are pretty localized and simple.

However, in order to make the code cleaner, we introduce the new helper class **NextState** inside TDNTuple2Agt, which bundles the information needed for state advance. This requires more code changes, but the resulting code is better understandable and thus better maintainable. We use class NextState in trainAgent() and related functions.[[5]](#footnote-5)

### Results

Is there a measurable benefit of using afterstates in 2048? – Yes, it is! We run 10 times on a TDNTuple2Agt loaded from ‘10 4Tupel 10k TDNT2 afterState.agt.zip’, one time with AFTERSTATE, one time w/o. The results are stored in [multiTrain-2048-with[no]AFTERSTATE.csv](file:///C:\user\datasets\Vorlesungen\FHK\DiplomArb\2016\BA%20Kutsch\multiTrain-2048-withAFTERSTATE.csv), and processed with [multiTrainPlot.R](file:///C:\user\datasets\Vorlesungen\FHK\DiplomArb\2016\BA%20Kutsch\multiTrainPlot.R) to get this graph:



The AFTERSTATE==true case has results which are consistently 30%-60% better!

### Some other items

* OK: Quick Eval’s Average Score after 50 games is varying a lot in game 2048. Might be due to low outliers? We tested whether a Median Score would be more stable. But it turns out, that median has similar fluctuations. The only way seems to be that we repeat Quick Eval multiple times (e.g. 10 times) and take the average of the Average Score (resulting in a smaller standard deviation, reduced by a factor (e.g. sqrt(10))).
* OK: multiTrain: add intermediate evaluations and print results to file 🡪 visualization of multiple trainings in R: see [multiTrain-2048-with[no]AFTERSTATE.csv](file:///C:\Users\wolfgang\AppData\Roaming\Microsoft\Word\agents\2048\csv\multiTrain-2048-withAFTERSTATE.csv), and visualization with [multiTrainPlot.R](file:///C:\Users\wolfgang\AppData\Roaming\Microsoft\Word\resources\multiTrainPlot.R) and similar R-files.
* OK: Extend multiTrain file saving to go in the right directory for each game. – Done: multiTrain.csv is saved to agents/<gameName>[/subDir]/csv.
* OK: Rename MaxScore in getNextAction() to BestScore (to disentangle from so.getMaxGameScore())
* OK: Extend pa.stringDescr() by the new elements: AFTERSTATE, learnFromRM. (chooseStart01 may be added when we have ParOther as part of TDNTupleAgt).
* OK: Make ε-update the same ([epsLinear](#epsLinear)) in TDAgent, TDNTupleAgt, TDNTuple2Agt.
* OK Simplify TDNTuple2Agt::trainAgent (withNS always true, comment out the two parts tagged with ‘this part will become obsolete’. But perform tests that the train behavior is exactly the same (no dangling reference to ‘old’ variables)
* OK: Parameters of tab ‘Other par’ are as well relevant for training (like ‘Choose Start 01’ or ‘Learn from RM’) and evaluation (like Quick Eval Mode). It is better if they are also part of the saved agent. – Done for TDNTuple2Agt, TDNTupleAgt, TDAgent: Added a new class ParOther. Added a member ParOther m\_oPar to all those agents. It does not invalidate the already stored agents. But some code is needed in XArenaMenu::loadAgent() in order to safely load older agents.   
  Added m\_oPar as well to MC, MCTS and MCTSExpectimax agents, it may be useful to store the quick evaluator mode used.
* OK: Simplified the interface for PlayAgent::trainAgent(so,learnFromRM,epiLength): both parameters learnFromRM and epiLength are no longer needed, they are retrieved from m\_oPar.
* Heap space: When loading the big 44MB-agent (FIXEDNTUPLEMODE=2) and then starting the training anew, we get sometimes a heap space error, even with VM-argument -Xmx1024M. Look for memory leaks!
* Possible extension: Currently, TD-NTuple plays always with 1-ply look-ahead. It would be an option to offer n-ply look-ahead. This requires more computational effort during game play, but probably results in stronger agent play. Needs some thinking how to establish n-ply look-ahead in nondeterministic games: Only one random playout? Multiple playouts and taking the average? Or the worst result?
* OK Little bug: StateObserver2048 implements StateObservationNondeterministic, but StateObs2048BitShift and StateObserver2048Slow still implement StateObservation. – Done.
* OK Can we speed up TDNTuple2 training for 2048 if we create an invisible GameBoard class GBInvisible2048 which eliminates any drawing and painting on JFrame? – No, a quick implementation with GBInvisible2048 has the same runtime. We moved GBInvisble2048 to deprecated.

## Alpha decay

The learn step size α follows this decrease scheme from αi to αf:

This starts with αi at N=0 and ends with αf at N=Nmax.   
In between it follows an **exponential decay scheme**:

We see that β gets a large negative value as approaches 0. (The value is not allowed, it would lead to infinite β.) We have to keep in mind that an leads to large negative β and thus a steep and fast decline towards .

## Rewards other than game score

* From discussion with Laurenz 2017/10: Currently we use the game score as reward signal. But the game score does not distinguish a good from a bad player **while the game is underway**: The score is mainly linearly rising with number of moves in an episode. A better indicator of good play might be the (cumulative) number of empty tiles.   
  To test this hypothesis: Record during an episode both measures, the score and the cumulative number of empty tiles. Play one game with a good agent, another one with a bad agent. The expectation: As long as both game continue, the cumulative score plots look similar. On the other hand, the cumulative empty tiles plots should be significantly higher for the good agent than for the bad one. 🡪 partly fulfilled, see images in [resources\R\_plotTools\playStats.zip](file:///C:\Users\wolfgang\AppData\Roaming\Microsoft\Word\resources\R_plotTools\playStats.zip).

## Games with multi-moves per turn

There are deterministic games like Kalah where the game rules allow it that a player performs (in certain game states) more than one action (move) if it is their turn. We call a turn of a player with multiple moves a **multi-move**.

TODO: Think about Backgammon (nondeterministic, multi-move)

Multi-moves require a bit more complex action in getNextAction() and other places:

(actBest, V) = getNextAction(so, random, …)

see [TR-TDNTuple.pdf](file:///C:\user\wolfgang\www\Optimierung\TR_GBG\TR-TDNTuple.pdf)

(the **multi-move** part: If action ak calls for a next move of the same player, then search the best among these follow-up moves. Set V(ak) = V(best follow-up move). Do this recursively, if one of the follow-up moves allows another extra move!)

PlayAgent()

while (nextPlayer==curPlayer) do: another move!

trainAgent()

same as before, we have only to select always the right player via StateObservation. Each move in a multi-move gets a separate update of weights (however, the decision which next action to take during training are based on multi-move getNextAction()).

But question: What is the right next state V(st+1) for the target in an update step?

OK: make a better ACTIONS class

class ACTIONS\_VT extends ACTIONS with new members double[] vTable, double vBest

ACTIONS\_VT getNextAction2(…) is now the new alternative to ACTION getNextAction(…)

OK Changes needed for the other agents

* NEW\_GNA
* selector function getNextAction, old getNextAction becomes getNextAction1. New functions getNextAction2,3 returning an ACTIONS\_VT object
* normalize2()
* getGamma()

MCAgent: How does getNextAction1MultipleAgents() reflect the loop over multiple agents? - It returns in vtable[k] how many of the multiple agents selected k as the best next action

**TODO**:

* OK Think about the multiplication of reward with player pt during training. Shouldn’t it be the same pt when taking the difference “reward – oldReward” ?? – This was a problem of the old version (VER\_3P=false, NEW\_2P=false). It was correct, since reward was from a different player’s perspective than value function. However, it was not very ‘logical’ or easy to grasp. Now we have two alternatives (NEW\_2P=true or VER\_3P=true), where we do not need to multiply with a player-sign variable in an unsystematic way.   
  See [Konen2017b] ([TR-TDNTuple.tcp](file:///C:\user\wolfgang\www\Optimierung\TR_GBG\TR-TDNTuple.tcp)) for details.
* OK Add { trnMoves (pa.getNumTrnMoves()) } to each line of multiTrain.csv
* OK Add { alpha, epsilon } to pa.stringDescr2()) for TD-agents pa and print it as 2nd line of multiTrain.csv
* OK Transform MCTSExpectimaxAgt to use class ParMCTSE instead of MCTSExpectimaxParams (big class extending frames)
* OK When all agents have the new ACTIONS\_VT getNextAction2(…) returning an object of class ACTIONS\_VT:
* OK change all calls of ACTIONS getNextAction(…,VTable,…) to ACTIONS\_VT getNextAction2(…)
* OK handle the VTable part, where necessary
* OKIf everything works, remove the selector functions getNextAction(…) and the now obsolete ‘old’ functions getNextAction1 in every agent
* OK TD-NTuple-2: horizon printout in stringDescr()

## Debugging VER\_3P=true, MODE\_3P=0 (former OLD\_3P=true)

The VER\_3P=OLD\_3P=true switch in TDNTuple2Agt is our first attempt to develop a TD-learning scheme for n-player games with arbitrary number n of players. I.e. it should allow the same algorithm for n=1,2,3,…

The technique and the equations behind VER\_3P and NEW\_2P are described in much more detail in [Konen2017b] ([TR-TDNTuple.tcp](file:///C:\user\wolfgang\www\Optimierung\TR_GBG\TR-TDNTuple.tcp)). Here we cover some software issues with VER\_3P=OLD\_3P=true:

1. The branch VER\_3P works for 2048 (1-player games), but not yet for 2-player games.
2. After fixing the 1st bug (see below), it works in principle, but there is a decrease in performance with NEW\_3P.

**ad 1)** Since VER\_3P=OLD\_3P=true cannot even learn the trivial 2x2 Hex, there must be a fundamental sign bug.

Different debug printouts did not clarify the reason at first.

Suspicious items

* The DBG\_REWARD printout after the call to trainNewTargetOLD\_3P in trainAgent did show that reward and reward2 are NOT the same if nextSO is a win for the 2nd player (W). Is this correct?
* trainNewTargetOLD\_3P calls updateWeightsNew with curPlayer=nextPlayer=i (i=0,1). Is this correct?

We looked more precisely into the updates of the value function(s) in the states prior to a final state.

After 2 more hours of looking ☺, the bug was found: The problem was in g3\_evaluate with the line

agentScore = getScore(NewSO);

This was wrong for NEW\_3P, since getScore(so) always retrieves the score from the perspective of so.getPlayer(). This was the right thing to do as long as NEW\_3P==false, since we need in this case according to Eq. (9) in [Konen2017b]. But it is the wrong thing to do if NEW\_3P==true. What we need then is which is given by

agentScore = getScore(NewSO, refer.getPlayer());

where refer is the state preceding NewSO.

**Now the results for VER\_3P=true or =false are much closer for TTT and Hex** (sizes 2 and 4 tested so far).

**ad 2)**

But the results are not identical.

A closer look with multiTrain reveals, that VER\_3P=NEW\_3P=true (although being much better after the getScore bug fix above) is still not as good as NEW\_3P=false:



(GBG\agents\Hex\04\csv\multiTrain-learnFromRM-NEW\_3P-small.png, created with GBG\resources\R\_plotTools\multiTrainPlot-learnFromRM.R).

All curves are the average from 25 runs and the evaluator has mode 10 (success against MCTS when TD-agent starts from different winning start boards). It is clearly seen that the curves with “… 3P” (the ones with VER\_3P=true) are worse than those without (those are the ones with VER\_3P=false). The difference is more pronounced in the (learnFromRM==true)-case.

But why is there still this discrepancy?

We spent hours of looking and debugging: We built under switch DBG\_OLD\_3P inside TDNTuple2Agt a second m\_Net3 which updates according to VER\_3P=false (even if the global setting is VER\_3P=true) and compare the update steps. When do both nets start to deviate in their decisions?

It was seen that quite early the 3P-form would have Vold ≠ 0 for final states, while the 2P-form still had Vold=0.0. After more iterations, cases with Vold ≠ 0.0 would also appear in the 2P-form, but not so often and not so big. The update step in updateWeightsNewTerminal() would bring Vnew closer to 0.0, but it is of course a burden for the algorithm: As long as Vnew for final states deviates significantly from 0, the target for the preceding states (and their predecessors) will be wrong.

It is probably not a software implementation bug, but a ‘feature’ (or fundamental flaw) of the 3P-algorithm: This algorithm updates the n-tuple value functions twice as much (for 2 players), and it does so even for the value function of the player who is not the moving one. This might more often bring one of the n-tuples in a state where it gives a value different from zero to final states (unwanted cross talk). The 2P-form has fewer cross-talk[[6]](#footnote-6). For the general n-player form with arbitrary value functions we probably cannot do better than in the 3P-form. But for games with 2 players and strictly antagonistic reward functions[[7]](#footnote-7), it is probably better to stick with the 2P-form.

To put it otherwise: the 3P-form updates for twice as many states the value function away from zero. This leads to more ‘cross talk’ between n-tuples than necessary. This explains probably, why the 3P-curves in the plot above decrease in iterations 85.000-100.000: The random move rate goes to zero, and – since ‘Learn from RM’ is false – the update frequency increases and so the cross-talk increases. This leads to performance degradation.

Ways out:

* ~~Add a predicate StateObservation::has2OppositeRewards() to all games: This predicate is true, if it is a 2-player games with antagonistic reward function. It is false in all other cases.~~
* ~~When has2OppositeRewards()==true, run the 2P-form. In all other cases run the 3P-form.~~

[obsolete now, we use the new perspective (VER\_3P=true, OLD\_3P=false)]

* We advise with the new switch NEW\_2P=true an equivalent form to the old 2P-form (NEW\_2P=false). This new 2P-form avoids the p=+1/-1 parameter and is described in more detail in Appendix C of [Konen2017b] ([TR-TDNTuple.tcp](file:///C:\user\wolfgang\www\Optimierung\TR_GBG\TR-TDNTuple.tcp)). If the new form is tested and performs as well as the old form, eliminate the old form, i.e. have always NEW\_2P=true. Later simplify the code.
* Another perspective: Think about other alternatives to VER\_3P=OLD\_3P=true, which are valid for 3 and more players, but which reduce to the NEW\_2P-form (or produce results equivalent to it) in the case of 2-player games with antagonistic reward functions:
  + like in TD-Gammon: for an n-player game make an n-ply look-ahead and take this action which maximizes the Z-score Z(self, one-round-ahead)
  + for antagonistic-reward n-player games[[8]](#footnote-8): make an (n-1)-ply look-ahead (all opponents of self) and take that action which maximizes

Both alternatives need to be worked out in more detail. They are perhaps even algorithmically equivalent. In both cases there would be only **one** update of the value function (that of the current state). Both cases should reduce to the NEW\_2P-form in the case of 2-player games with antagonistic rewards.

TODO:

* OK Work out the VER\_3P alternative cases in more detail.
* We probably need to rebuild all Hex agents stored in agents/Hex/, because agents created with NEW\_2P=false will not work under NEW\_2P=true (other meaning of V()).
* OK We should later delete all Hex agents stored in agents/Hex which are from class TDNTupleAgt, they lead to confusion with TDNTuple2Agt. In the future we should use only class TDNTuple2Agt.

## Debugging VER\_3P=true, MODE\_3P=1 (former OLD\_3P=false)

We worked out the TD-Gammon alternative. Details are in [Konen2017b] ([TR-TDNTuple.tcp](file:///C:\user\wolfgang\www\Optimierung\TR_GBG\TR-TDNTuple.tcp)).

After some initial debugging: It **works nicely for nply≤NP** for all three games TTT, 2048, Hex. The case (nply=1, NP=2) is equivalent to the former (NEW\_2P==true)-form. The case (nply=2, Np=2) is for 6x6-Hex costly to calculate (10h training instead of 1h (!!)) and is only slightly better than the (nply=1)-case. This is due to the high branching factor of 6x6-Hex (18 on average).

We expected nply=2 to work faster on 2048 than on 6x6-Hex, but we found a BUG: **nply=2 leads to infinite weights**, infinite getScore (and finally a crash) on 2048. **Reason not yet found**. May be that 2048 is nondeterministic and nply-branch cannot handle this (i.e. the former problems before afterstate are back)? When [[Jaskowski16]](file:///C:\WUTemp\FH-MassenDaten\svnSoma\trunk\doc\CaseStudies.d\201314.d\CIG2014\MCTS.literature\2048\Jaskowski2016-2048.pdf) talks about “n-ply search”, he always means ‘coupling of the TD-n-tuple network (afterstate value function of the 1-ply afterstate) with n-ply expectimax search. So it is probably not worth to do n-ply in training, but it is better to couple a trained agent with an n-ply tree search (minimax in the case of deterministic games, expectimax in the case of nondeterministic games). OK, done with MaxNWrapper and ExpectimaxWrapper, works nicely for 2048: our best TD-NTuple2 agent with score

OK Bug: nply=3 in 4x4-Hex leads to wrong moves covering already occupied tiles. Fixed: It was a missing “g3BestScore = -Double.MAX\_VALUE;” in g3\_Eval\_NPly. We get these results for 4x4-Hex

* nply=1 is fastest in computation time, but slower-learning in terms of training games and less stable (evalQ=1.0 may be fall back to lower values in later games).
* nply=2 or 3 is slower in computation, but learns more reliably to win after 20.000 games. Once evalQ reaches 1.0, it usually stays there. There is no perceivable difference between 2 and 3.

(These are first results only, repeated runs are necessary to confirm results)

## Max-N and Expectimax-N

We added two new agents MaxNAgent and ExpectimaxNAgent which are the generalization of Minimax to N players for deterministic and nondeterministic games.

We added two wrapper agents MaxNWrapper and ExpectimaxWrapper (for QuickEval & nPly>0 we implemented a parallel version on 6 cores for faster execution, yielding 10 min for nPly=5 instead of 1h single-threaded. The moves/second measurement should still be realistic.)

QuickEval results for TD-NTuple-2 agent with FIXEDNTUPLEMODE=2 [Jaskowski2016, 4 6-tuple] and 200k training games and 50 QuickEval games:

|  |  |  |  |
| --- | --- | --- | --- |
| nPly | avg score | highest tile | moves/second |
| 0 | 108.000 | 8192: 21/50 | 94.620 |
| 1 | 108.000 | 8192: 25/50 | 56.800 |
| 3 | 150.000 | 16384: 1-2/50 | 20.048 |
| 5 | 182.000 | 16384: 9/50 | 582 |

(needs to be repeated to get a more reliable std. dev. and average)

## Useful Parameter Settings

### 2048

TD-NTuple-2: ε =0, α =0.2🡪0.1, λ =0, NO output sigmoid, USESYMMETRY, AFTERSTATE, FIXEDNTUPLEMODE=1 [Jaskowski2016, Fig. 3b, 5 4-tuple], 10.000 games 🡪 Quick Eval Score approx. 34.000 (see figure in [Sec. Results](#ResultsAfterstate))

TD-NTuple-2: ε=0, α=0.2🡪0.1, λ=0, NO output sigmoid, USESYMMETRY, AFTERSTATE, FIXEDNTUPLEMODE=2 [Jaskowski2016, Fig. 3c, 4 6-tuple], 40.000 games (0.5h) 🡪 Quick Eval Score approx. 50.000 (!), but mighty LUT: Even as ZIP, the agt.zip is 44 MB (!, now deleted).

Training the same agent for 100.000 games (0.9h) 🡪 Quick Eval Score approx. **80.000** (!! **best so far**), but even larger ZIP: 69 MB (!). Highest tiles reached in 200 eval games are: 29% 8192, **75% 4096**, 89% 2048 (!). See [agents\2048\fixed 4 6-Tupels 100k TDNT2 afterState.xlsx](file:///C:\Users\wolfgang\AppData\Roaming\Microsoft\Word\agents\2048\fixed%204%206-Tupels%20100k%20TDNT2%20afterState.xlsx).

Training the same agent for 200.000 games (3.0h) 🡪 Quick Eval Score approx. **108.000** (!!), but even larger ZIP: 92 MB (!). Highest tiles reached in 200 eval games are: **48% 8192**, 46% 4096, 5% 2048 (!). See [agents\2048\fixed 4 6-Tupels 200k TDNT2 afterState.agt.zip](file:///C:\Users\wolfgang\AppData\Roaming\Microsoft\Word\agents\2048\fixed%204%206-Tupels%20200k%20TDNT2%20afterState.agt.zip) and [resources\R\_plotTools\multi-100k-200k-TDNT2-afterstate.png](resources/R_plotTools/multi-100k-200k-TDNT2-afterstate.png). And there seems still to be potential in the learning curve.

With ExpectimaxWrapper even higher results

**CAUTION**: Remember that ConfigGame.FIXEDNTUPLEMODE has to have the right value **in source code** when you want to retrain with similar results. Re-loading + re-train with wrong FIXEDNTUPLEMODE does NOT work. (Re-loading the agent and doing Play Game, Quick Eval or similar will however work).[[9]](#footnote-9)

(‘Choose Start 01’ and ‘Learn from RM’ are irrelevant here since we have no agent random moves.)

Note that [Jaskowski16] reports a 40% increase in score when changing α from 0.1 to 1.0.

Another thing to investigate: Is it true that our agent learns much faster than in [Jaskowski16] or [[SzubertJaskowski-CIG2014]](file:///C:\WUTemp\FH-MassenDaten\svnSoma\trunk\doc\CaseStudies.d\201314.d\CIG2014\MCTS.literature\2048\paper2048-SzubertJaskowski-CIG2014.pdf)? If so, why? (Most elements in TD-NTuple-2 are exactly as in [Jaskowski16]. But one thing different: we have perhaps the better update rule, where no index is updated twice in one round.)

### TicTacToe

TD-NTuple-2: ε=1.0🡪0, α=0.2, λ=0, output sigmoid, USESYMMETRY, random n-tuple 10\*6, 10.000 games, Quick Eval Mode 2 and Train Eval Mode 9 🡪 evalQ=0.0 after 2.000-3.000 games.

### 4x4 Hex

TD-NTuple-2: ε=1.0🡪0, α=0.5, λ=0, output sigmoid, USESYMMETRY, random n-tuple 20\*5, 100.000 games, Quick Eval Mode 0 (not 2) and Train Eval Mode 10 🡪 good Inspect initial board, evalQ=1.0, evalT=0.66.

TD-NTuple-2: ε=1.0🡪0, α=0.99, λ=0, output sigmoid, USESYMMETRY, random n-tuple 20\*5, 100.000 games, Quick Eval Mode 0 (not 2) and Train Eval Mode 10 🡪 good Inspect initial board, evalQ=1.0, evalT=1.0.

Remember that we need in ‘Other pars’ the checkboxes ‘Choose Start 01’ checked and ‘Learn from RM’ NOT checked in order to get good results.

The ideal InspectV initial board has +1000 on the vertical diagonal and -1000 everywhere else. A good approximation to it is routinely found by the agents.

### 5x5 Hex

Quick Eval Mode 0 (not 2) and Train Eval Mode 10

TD-NTuple-2: ε=1.0🡪0, α=0.5, λ=0, output sigmoid, USESYMMETRY, random n-tuple 25\*6, 150.000 games 🡪 good Inspect initial board, evalQ=1.0, evalT=0.9.

TD-NTuple-2: ε=1.0🡪0, α=0.2, λ=0, output sigmoid, USESYMMETRY, random n-tuple 25\*6, 150.000 games, 🡪 good Inspect initial board, evalQ=1.0, evalT=0.9.

The InspectV initial board for α=0.2 (right) shows roughly the win-lose-pattern found by Hexy (left):

W

L W

L W L

L W W W

L W W W L

W W W L

L W L

W L

W

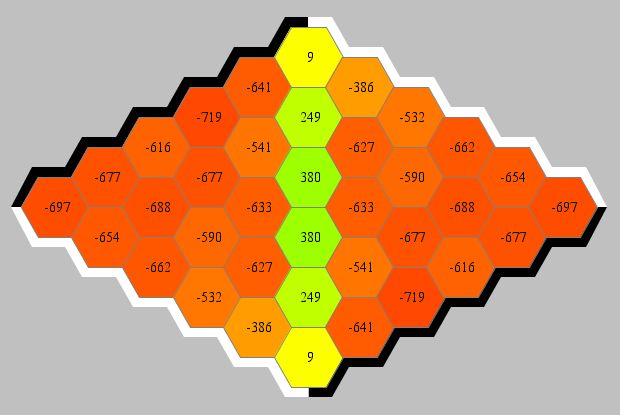
The diagram means: Black (1st player) loses (L) or wins (W) when he plays this first move.   
[It depends on the random factors of a run (which n-tuples and so forth), the InspectV initial board does not always mirror so nicely the true win-lose-pattern.]

Remember that we need in ‘Other pars’ the checkboxes ‘Choose Start 01’ checked and ‘Learn from RM’ NOT checked in order to get good results.

### 6x6 Hex

Quick Eval Mode 0 (not 2) and Train Eval Mode 10

TD-NTuple-2: ε=1.0🡪0, α=0.2, λ=0.5, output sigmoid, USESYMMETRY, random n-tuple 25\*6, 150.000 games, 🡪 good Inspect initial board, evalQ=1.0, evalT=0.9.

The InspectV initial board for α=0.2 (right) shows roughly the win-lose-pattern found by Hexy (left):

W

L W

L W L

L W W L

L W W W W

L W L L W L

W W W W L

L W W L

L W L

W L

W

The diagram means: Black (1st player) loses (L) or wins (W) when he plays this first move.   
[It depends on the random factors of a run (which n-tuples and so forth), the InspectV initial board does not always mirror so nicely the true win-lose-pattern.]

Remember that we need in ‘Other pars’ the checkboxes ‘Choose Start 01’ checked and ‘Learn from RM’ NOT checked in order to get good results.

TD-NTuple-2: ε=1.0🡪0.2, α=0.2, λ=0.5, output sigmoid, USESYMMETRY, random n-tuple **250\*4**, 150.000 games, 🡪 good Inspect initial board, evalQ=1.0, evalT=0.9.

1. with tmin = 0 or 1 depending on whether we know the afterstate s’0 preceding s0 or not. [↑](#footnote-ref-1)
2. Which initial moves are losing moves? – For small boards up to 4x4 this can be calculated by Minimax, for larger boards this is not viable. But we can ask Hexy (or another strong Hex player) whether it can win as 2nd player after a certain initial move. [↑](#footnote-ref-2)
3. Of course this is inherently a flaw of the design: It is nicer if the information whether to use symmetry or whether to use sigmoid is stored only in one place. We changed it accordingly in TDNTupleAgt, TDNTuple2Agt, NTupleValueFunc, NTuple2ValueFunc. [↑](#footnote-ref-3)
4. A better solution would be to issue a warning when Minimax is attempted as Evaluator and the Hex board is too large. It should also be more transparent which the settings of the counterpart agent are. Perhaps with a new window showing the evaluator settings? [↑](#footnote-ref-4)
5. We tried to use class NextState in getNextAction() as well, but we found that this slows down training dramatically (40% - 70% slower!), so we stick in getNextAction() to the old version. [↑](#footnote-ref-5)
6. since it updates only once and ‘steals’ the target from the successor state of the other player’s value function [↑](#footnote-ref-6)
7. antagonistic reward function: R(st|p(0)) = – R(st|p(1)) for all st [↑](#footnote-ref-7)
8. reward is +1 for one player and -1 for all other players [↑](#footnote-ref-8)
9. Now changed to a safer design: Instead of ConfigGame.FIXEDNTUPLEMODE we have now m\_ntPar.fixedNtupleMode. – How to change fixedNtupleMode for an already trained agent? Start debugger, load agent, stop at a breakpoint, Right mouse - **Watch** on member m\_ntPar, change element fixedNtupleMode, save agent. [↑](#footnote-ref-9)