OpenMP parallelization of agent-based models

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Many complex systems are composed by many heterogeneous elements which interact with each other

A possible approach for studying such systems is Agent-Based Simulation.

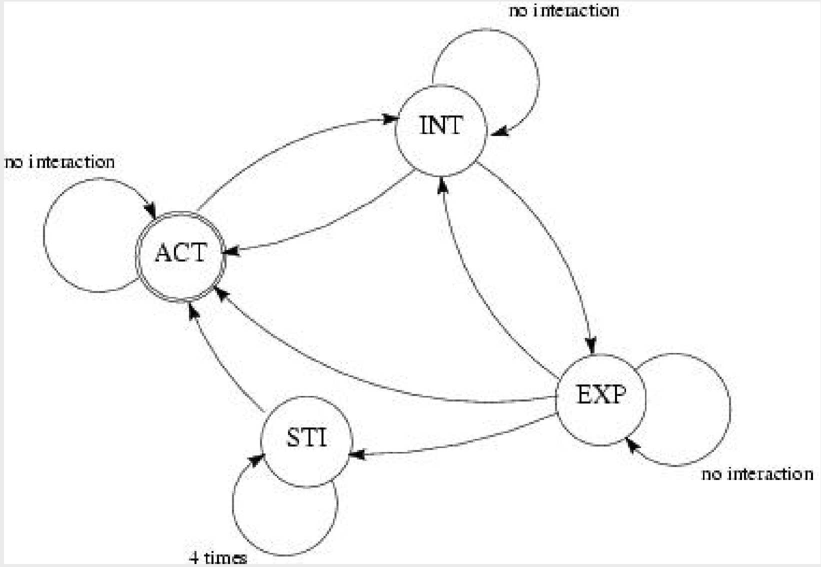
An Agent is an entity which has:

- an internal data representation (memory or state)
- means for modifying its internal data representation (perception)
- means for modifying its environment (behaviour)

The complex perception/behaviour of the entities corresponds to precise *state-changes* upon interaction.

Every single entity can be thought of as a Stochastic Finite State Machine (SFSM) which processes information and changes its state according to the result of the interactions with other entities, or with the environment.

There is a very limited number of floating point operations in an Agent-Based simulation. Most of the data structures are a combination of integers and pointers.



Application I: Immunology

The whole automaton corresponds to a single lymphnode

- the space is defined as an hexagonal 2D lattice
- the dynamics is probabilistic
- the evolution of each site depends just on the site itself (*internal dynamics*), but:
- entities move from site to site (*diffusion process*)

Entities on the lattice are the major classes of cells of the Lymphoid lineage (TH, CTL, B, PLB) and some of the Myeloid lineage (MA, DC)

Application II: Financial Markets

Three kinds of agents, trading with different strategies for a set of N assets (stocks, commodities, etc.)

Fundamentalists consider a reference (or "fundamental") value to determine the "right" price of an asset

Noisy traders do not follow any reference value and do not look at charts. Their behaviour is mostly random. There is a very high number of noisy traders but most of them have a very limited capital at their disposal

Technical traders also called *chartists* represent those agents who take into account information about the evolution of the price (in our case the moving average over certain time horizons)

An agent is not a broker: broker = collection of agents

Trading Strategies

Fundamentalists

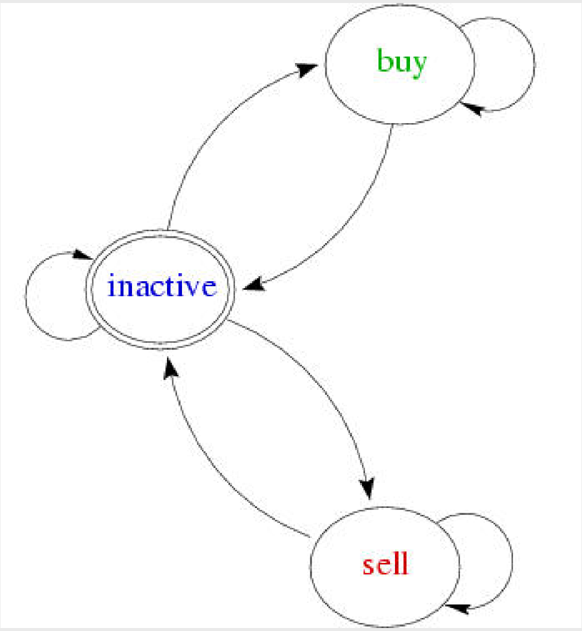
buy if p_t <= f_t
otherwise sell

Noisy

buy and sell randomly (probability 1/2)

Chartists

sell if $MA_t(h) > p^+$
buy if $MA_t(h) < p^-$
otherwise stay inactive

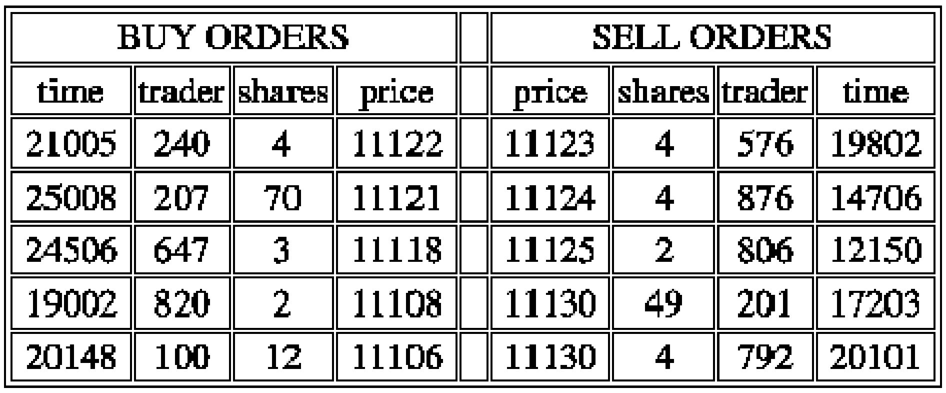


A generic agent data structure

```
typedef struct tagAgentblock {
    int aclass;                          /* agents type identifier   */
    int atid;                            /* type of moving average   */
    int strategy[MAX_NUM_ASSETS];        /* buy-sell decision        */
    int nstocks[MAX_NUM_ASSETS];         /* num. of possessed stocks */
    int ordertime[MAX_NUM_ASSETS];       /* time an order may be outstanding
                                            ordertime=0 means market order
                                            >0 means limit  order
                                            <0 means stop order */
    double orderprice[MAX_NUM_ASSETS];   /* orderprice:
                                            ordertime>0 means limit price,
                                            ordertime<0 means stop price,
                                            no meaning if ordertime==0 */
    double money;                        /* liquidity: available money
                                            not blocked in any order */
    double iwealth;                      /* initial wealth           */
    double invested[MAX_NUM_ASSETS];     /* money invested in stocks */
    double activity;                     /* probability to trade */
    void (*policy[NSTRATEGIES])();       /* strategy function */
    struct tagAgentblock *next;
} AGENTBLOCK;
```

The Book of Orders!!!

The “interaction” on each asset is regulated by a *book-of-orders* defined by lists of buy-orders and sell-orders



BUY ORDERS					SELL ORDERS			
time	trader	shares	price		price	shares	trader	time
21005	240	4	11122		11123	4	576	19802
25008	207	70	11121		11124	4	876	14706
24506	647	3	11118		11125	2	806	12150
19002	820	2	11108		11130	49	201	17203
20148	100	12	11106		11130	4	792	20101

Orders are stored according to type (buy or sell), price (descending and ascending) and time, operating on singly linked lists

A transaction occurs whenever the cheapest price among the sell list matches the most expensive offer in the other list

Matching orders are immediately satisfied (filed) whereas the rest wait for the arrival of a matching order for a time defined in the order itself.

The simulation

```
Repeat forever                                        [Oh, well…]
   Update fundamentalists' models                     [stochastic]
   While no price changes
           Pick another agent                         [order is not important, fairness is!]
           Have it take a decision
           If not inactive
              Decide what to trade, and how much
              Decide the order type                   [market or limit order?]
              Check if it has enough resources to buy/sell
              Post the order in the BO                [possible contentions!!]
              If order can be fulfilled
                      Update involved agents          [possible contentions!!]
                      Possibly update price           [possible contentions!!]
   Save info, compute moving averages, …
```

…and orders could expire so check now and then [to contend or to serialize?]

Relevant issues

Distributing agents among threads

- Probable contentions for Book of Orders
- Dynamic lists of orders
- Agent competition has to be fair
- Price updates while agents are trading
- Periodic removal of expired orders: possible races

Distributing Book of Orders among threads

- Probable contentions for agents' money boxes
- False sharing on agents' assets
- Load balancing (stocks can become inactive for a while)

Usual (and boring) stuff

- RNGs
- mallocs

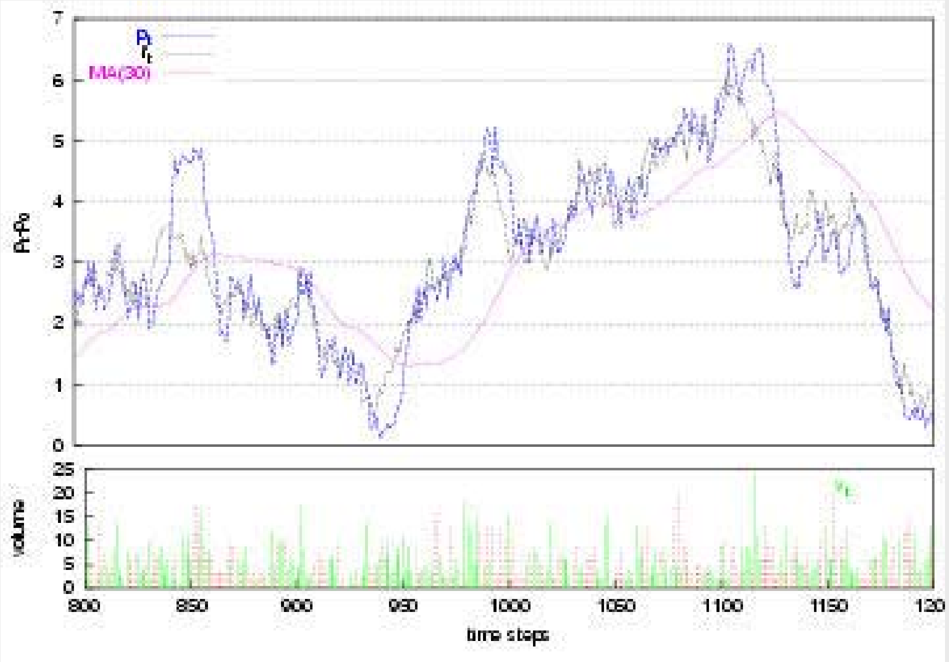
Questions?

Comments?

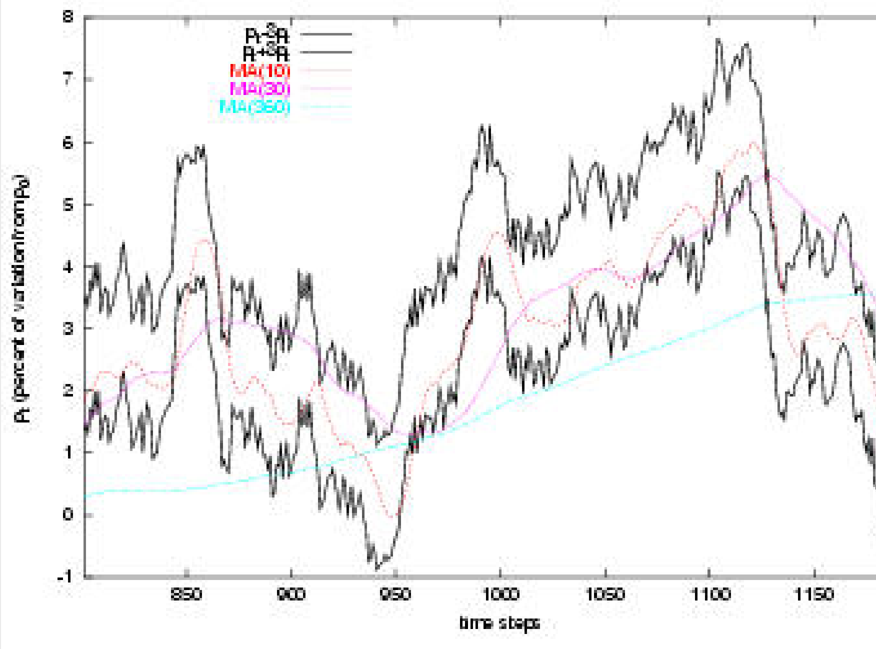
Suggestions?

Ideas?

Application II: Financial Markets



Asset price



Moving averages

L^2=400, N=18000