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ADVANCED TECHNIQUES FOR IMPROVING INDIRECT BRANCH PREDICTION ACCURACY

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THE PAPER OBJECTIVES

- To show the importance and the necessity of indirect branch / call prediction with very high degrees of accuracy.
- To prove that branch's history (always *taken* for indirect jumps) is insufficient for a good branch correlation and as a consequence, for high prediction accuracy.
- To develop some new prediction schemes more simple and feasible to be implemented in hardware.

THE IMPORTANCE AND THE NECESSITY OF INDIRECT BRANCH PREDICTION

- **Indirect branch prediction misses start to dominate the overall misprediction cost**
  - Predicative execution implies decreasing of conditional branches number.
  - The dimension took by the desktop, visual or object-oriented applications development
  - the portability trend of many of them
  - Because the target of an indirect jump (call) can change with every dynamic instance of that jump, predicting the target of such an instruction is really difficult

- **The overall performance of architectures are very sensitive to indirect branch prediction**
  - the Pentium4 equivalent processor performance degrades by 0.45% per additional branch missprediction cycle.
  - a very small number of static indirect branches is responsible for more than 90% of dynamic indirect jumps

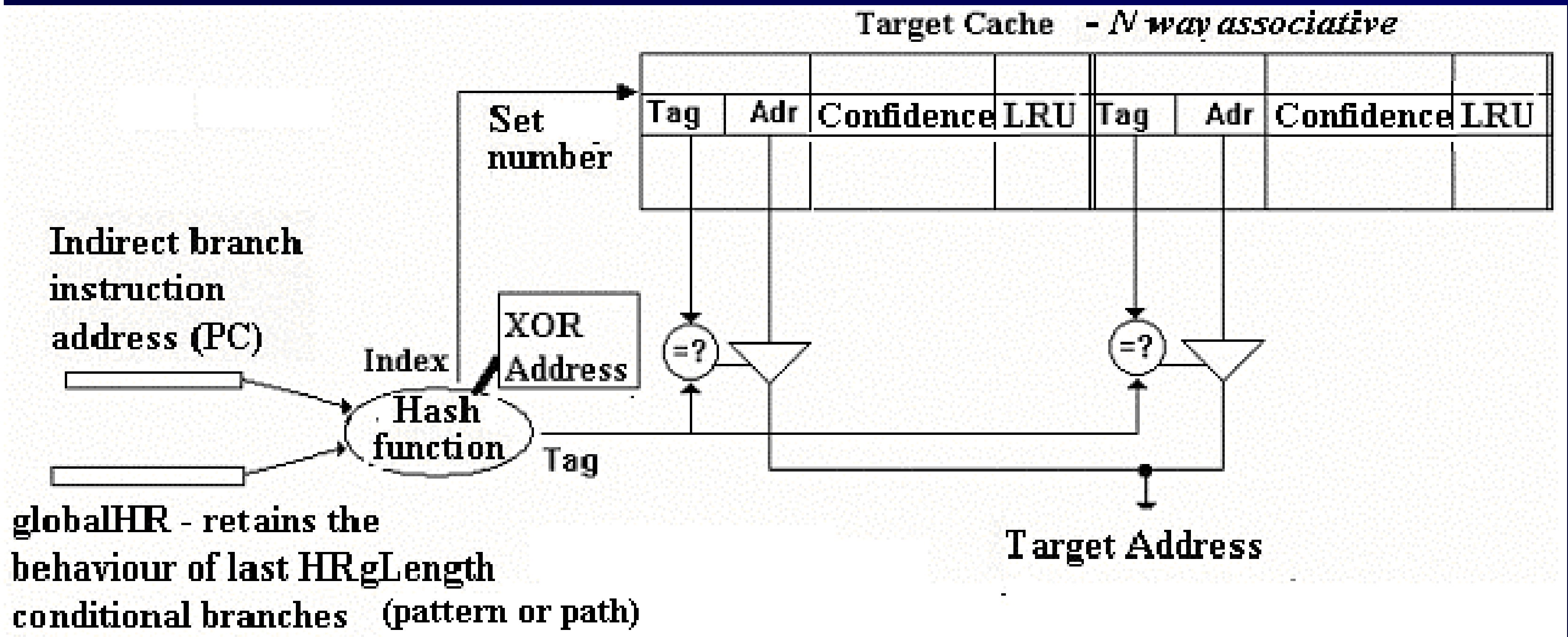
- **The maximum prediction accuracy obtained by a feasible PPM predictor and reported in literature is around 90% implies the necessity of implementing new efficient indirect branch prediction schemes**

EXTENDING TARGET CACHE STRUCTURE WITH A CONFIDENCE MECHANISM

- The native Target Cache predictor was proposed by Chang in 1997. Is a Two Level Adaptive branch prediction scheme that chooses its prediction from the last *N* targets of the indirect branch that already been encountered.
- A common criticism for all the present Two Level Adaptive Branch Prediction schemes consists in the fact that they used an insufficient global correlation information (HRg).
- The statistics point out, for the same static branch and in the same HRg and HRl context pattern, it's possible to find different ("alternative") branch's behaviors (for example about 50% taken and respectively 50% not taken), making that branch difficult to predict even through adaptive schemes.
- It's difficult correctly to predict a branch that has randomly behavior in the same prediction context (HRg, HRl). If each bit belonging to HRg (on k bits) will be associated during the prediction process with its corresponding PC, the correlation information will be more complete, the current branch's context becomes more precisely and therefore the prediction accuracy would be better.
- We developed a *path based predictor*, through extending the correlation information according to the above idea.
- The first level of history of Target Cache predictor records the path (the conditional branches' addresses) leading to the current indirect jump.

IMPROVING INDIRECT BRANCH PREDICTION ACCURACY BY SELECTIVELY IGNORING SOME PREDICTIONS

We implemented an heuristic for evacuation from set based on two independent information: *confidence* and *LRU*.



We introduce the parameter *threshold* which control the speculative process.

***if* (*confidence* >*threshold*) ⇨ we trust in prediction, the predicted value will be used *speculatively*.**

else **⇨we don't take into account about the prediction, the execution being made *non-speculatively*.**

Prediction accuracy ***(Ap) represents the probability that prediction generated by a high confident state to be correct.***

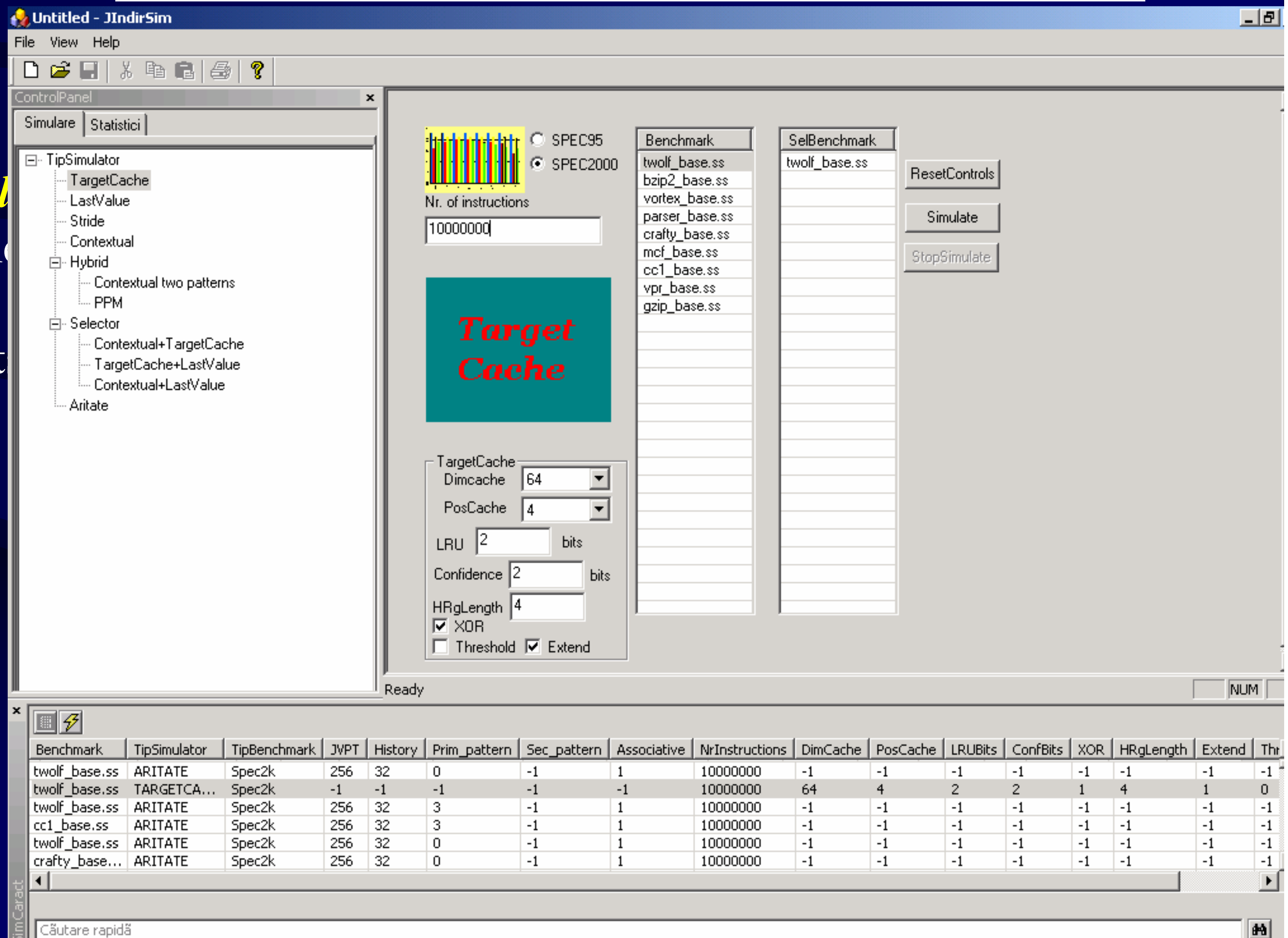
$$A_p = \text{Prob (correct prediction } | \text{ High confidence)} = \frac{HC_{corr}}{HC_{corr} + HC_{ntcorr}} \quad (1)$$

Usage degree **represents the** ***percentage of cases in which is made a prediction (high confident)*****, from the total number of dynamic indirect jumps from the program.**

$$\text{Usage (prediction performed degree)} = \frac{HC_{corr} + HC_{ntcorr}}{\text{Total\_indirect\_jumps}} \quad (2)$$

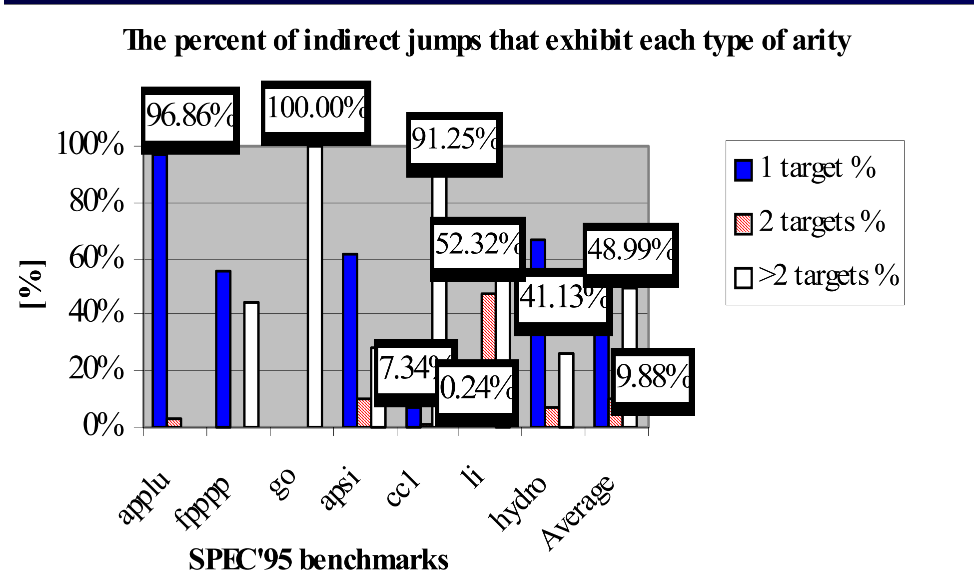
We define the ***overal[l] predictor performance*** th[e] product: **$P = A_p \cdot Usage$ (3).**
From (1), (2) and (3) result[s] that:

$$P = \frac{HC_{corr}}{\text{Total\_indirect\_jumps}}$$



PERFORMANCE METRICS

ARITY-BASED SELECTION HYBRID PREDICTOR.

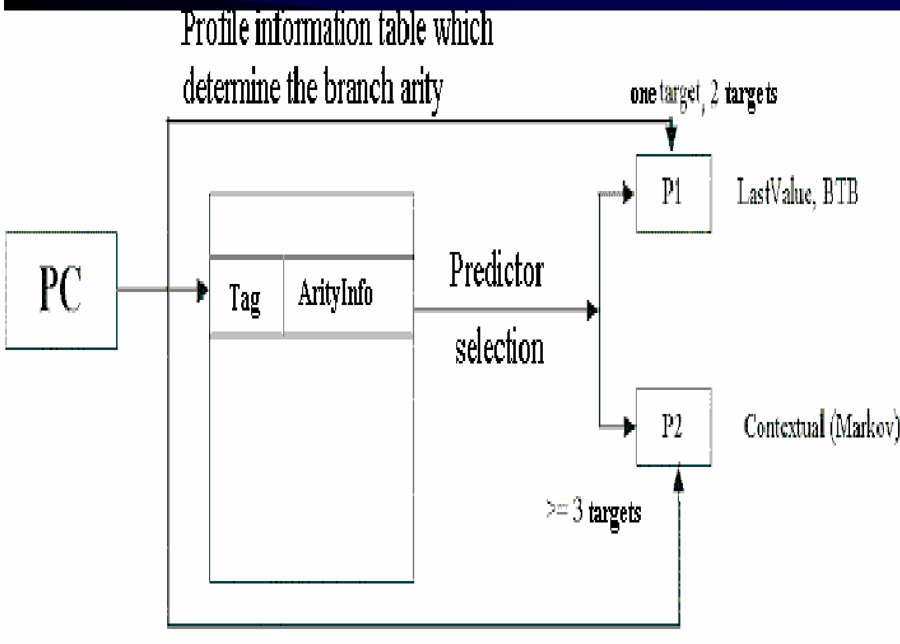


Arity **– the number of distinct targets generated by every instance of indirect branches**

monomorphic **– LastValue, BTB**

duo-morphic ***polymorphic***

Two Level Adaptive path-predictors (*path*= 2, respectively 3) and 1024 entries tables



Disadvantages

- ✓**The indirect jumps instructions should enclose in *opcode* field a counter for arity ⇔ an *extension of ISA*.**
- ✓**Depending on the input files used, *the profile information which determine the arity would vary*.**
- ✓***The classification of indirect jumps as duo-morphic doesn't represents always the best solution*** **(there are cases in which a such of jump has a predominant target).** ***Solution: branch classification function of situations number when occurs a target modification*.**

SIMULATION METHODOLOGY AND EXPERIMENTAL RESULTS

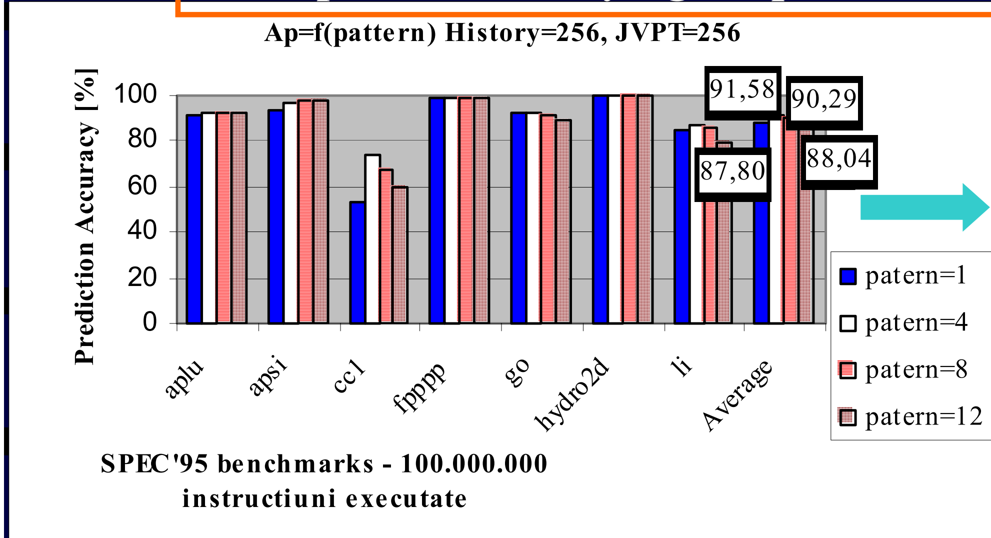
- We developed a cycle-accurate execution driven simulator derived from the *sim-outorder* simulator in the *SimpleScalar* tool set.

- We collected results from different versions of SPEC benchmarks: 3 integer (*li, go, cc1*) and 4 floating point (*applu, apsi, fpppp, hydro*) SPEC'95 benchmarks and 8 CINT SPEC2000 benchmarks.

- The number of instructions fast forwarded through before starting our simulations is 500 million in order to skip over the initial part of execution and to concentrate on the main body of the programs. Results are then reported for simulating each program for 200 million committed instructions.

RESEARCHES ABOUT LOCALITY AND PREDICTION OF INDIRECT JUMPS / CALLS

Prediction accuracy of **indirect jumps instructions using a complete PPM predictor, varying the *pattern length*.**

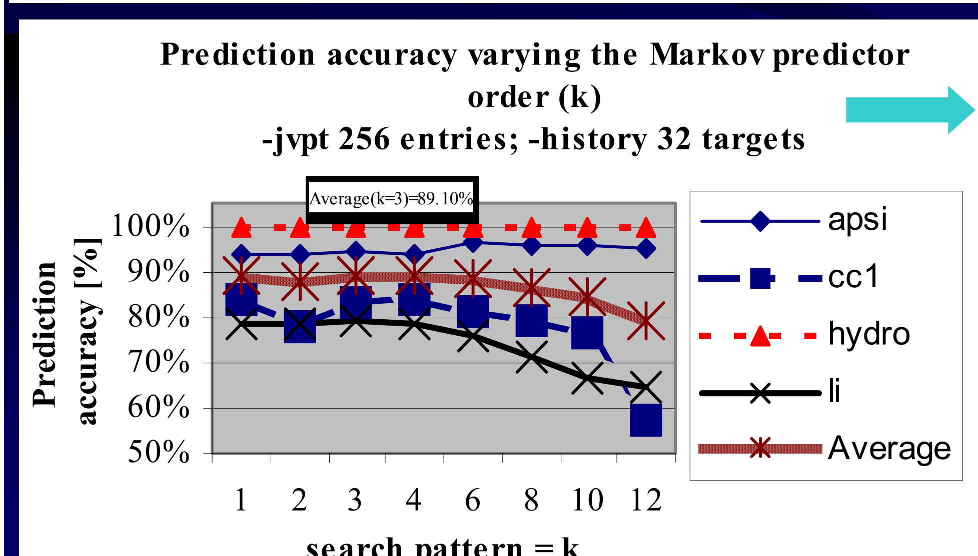


A rich search pattern ⇨ :

✍a higher prediction accuracy (+)

✍ *noise* ⇨ accuracy ⇘ (-).

The lack of hardware feasibility ilustrated by the complete PPM predictor requires the study of a simplified PPM predictor (encloses two Markov predictors of different orders – *m* and *n*).

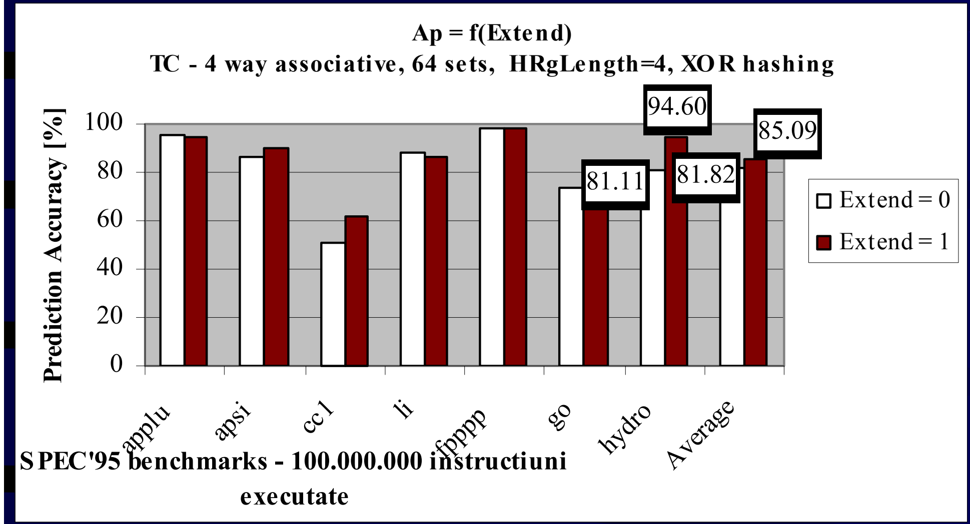


History↗ ⇨ it is distinguish a correlation between far away situated branches.

Ap(*contextual*;*history=**32**;pattern=**3*)=89.10% vs.

Ap(*contextual*;*history=**256**;pattern=**6*)=91.54%

Extending the correlation information to **identify with precision the context of indirect jump.**



- **At identical cost of implementing (Target Cache structure of same size) by *extending the correlation information* determine increasing the indirect branch prediction *accuracy (8.64% for HRgLength=4* respectively *15.16% when HRgLength=8).***

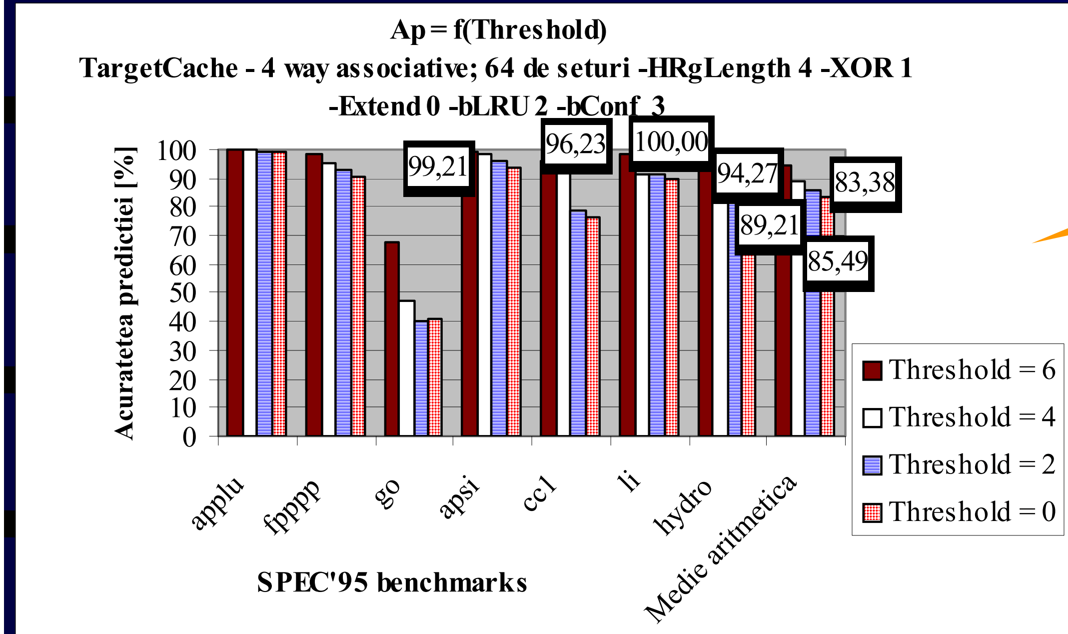
- ***Ap* (85.86%) is still lower than that obtained by the complete PPM predictor (89.33%) although there are remarkable results *(see hydro).***

XOR mode; TC – 4 way associative; 64 de seturi

	HRgLength = 4	**HRgLength = 8**
Extend = 0	76.52%	74.56%
Extend = 1	83.13%	**85.86**% (respectiv **88.21**% pentru un TC – 8 way associative)

Increasing the Indirect Jumps Prediction Accuracy by using a more precise context on benchmarks with the largest number of indirect jumps, using a TC – 4 way associative; 64 sets

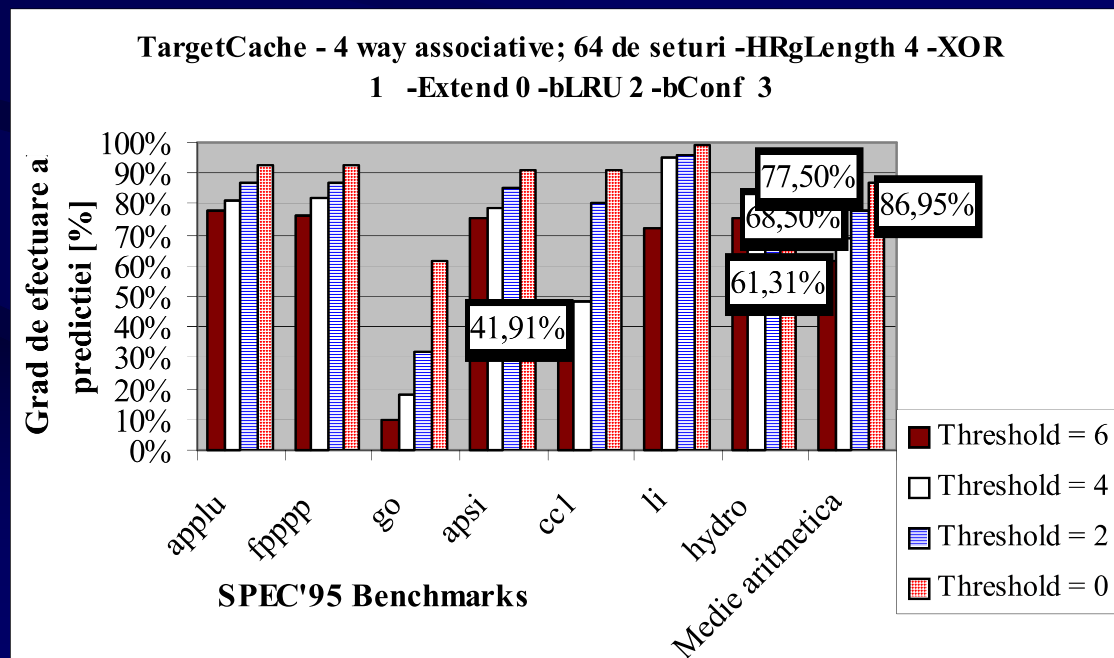
Improving indirect branch prediction accuracy by *selectively ignoring some predictions* .



Prediction Accuracy

The Prediction performed Degree (the Indirect Jump Fraction having Confidence>Threshold)

The probability that prediction generated by a high confident states (Ap) to be correct significantly increases through reducing the cases when the structure makes a prediction (between 3.57% and 11.45% depending the threshold). The disadvantage is that *the percentage of cases in which is made a prediction dramatically decreases*.



✓ Attaching a confidence automaton, the ***predictor overall performance is improved*** **when this is less selective.**

✓ The ***efficiency of extending correlation information is proved in this case once again*** **(predictors' overall performance increases with 5.62% approaching by the PPM predictors performance).**

	Prediction Accuracy (without confidence mechanism)	***Predictors' overall performance*** **(with confidence mechanism) - P**			
			Threshold = 1		**Threshold = 2**
associatively =2	78.15%	<	**79.39%**	>	77.91%
associatively =4	82.27%	<	**82.78%**	>	81.32%
associatively =8	82.35%	<	**85.13%**	>	83.87%

The confidence predictor performs better for a higher associatively degree of Target Cache structure

a. (TC - 64 sets -.HRgLength 4 - XOR 1 -Extend 1 -bLRU 2 - bConf 3)

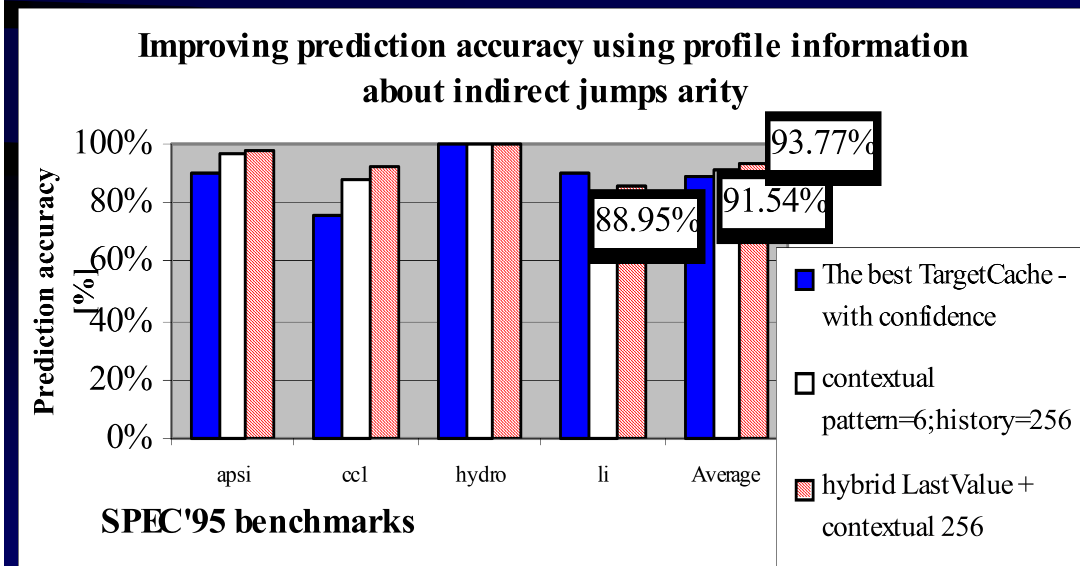
	Prediction Accuracy (without confidence mechanism)	***Predictors' overall performance*** **(with confidence mechanism) - P**		
		Threshold=0	**Threshold=1**	**Threshold=2**
associatively =4	86.40%	**< 87.39%**	85.66%	84.98%
associatively =8	86.47%	**< 88.88%**	> 87.17%	> 86.51%

b. (TC - 128 sets -HRgLength 8 -XOR 1 -Extend 1 -bLRU 2 - bConf 3)

Increasing the associatively degree greater than 8-way, the predictors' overall performance became asymptotical. **For a 8-way associative Target Cache predictor having 128 sets, keeping the behavior of last 8 conditional branches** ***P=88.97%, only with 0.4 % under the accuracy provided by a PPM predictor (89.33%).***

Our developed *hybrid predictor (LastValue+Contextual) with arity-based selection improves indirect branch prediction accuracy with percentages between 2.44% and 5.42% reaching in average 93.77%*, comparable with that reported in literature but more simple.

↗ performance using the hybrid predictor – JVPT=256, LVPT=256	**Contextual**	**Target Cache**
History = 32; pattern 3	3.03%	3.20%
History = 256; pattern 6	2.44%	5.42%



- **The significant percentage of polymorphic indirect branches and higher targets entropy specific for some indirect jumps fundamentally limits the indirect jumps prediction accuracy.**
- **The indirect jumps instructions should enclose in *opcode* field a counter for arity ⇔ an *extension of ISA*.**

CONCLUSIONS

- **We developed a hybrid predictor with arity-based selection that improves indirect branch prediction accuracy reaching in average to 93.77%, comparable with the more complex multi-stage cascaded predictor.**
- **If the context would permit it could be seen a correlation between branches situated at a large distance in the dynamic instruction stream.**
- **We showed that a modified Target Cache structure based on confidence mechanism and indexed with extended global correlation information represents a more simple and feasible solution that could replace the more complex PPM predictor.**

FURTHER WORKS

- **We try to improve the presented hybrid predictors,** in order to obtain better prediction accuracy **by introducing several different metapredictors, used for a dynamic selection of the current best predictor: some based on confidences and one based on a neural network.**
- **Testing the feasibility of an indirect branch predictor, based on dynamic decision tree, and sensitive to the most relevant features.**